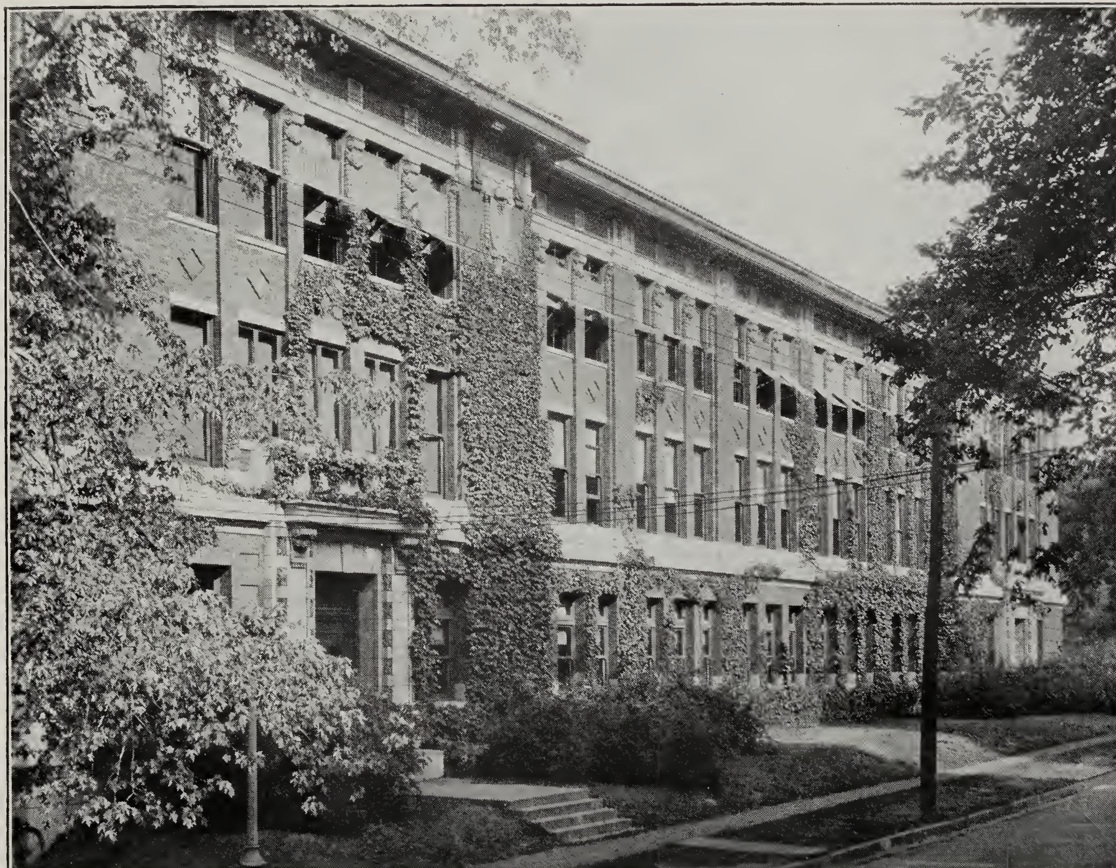
ILLINOIS
STATE GEOLOGICAL SURVEY

PAPERS PRESENTED AT THE QUARTER CENTENNIAL CELEBRATION OF THE ILLINOIS STATE GEOLOGICAL SURVEY



Home of the State Geological Survey, third floor Ceramics Building, University of Illinois

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*

BULLETIN NO. 60

Papers presented at the

QUARTER CENTENNIAL CELEBRATION

of the

ILLINOIS STATE GEOLOGICAL SURVEY

PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS
1931

STATE OF ILLINOIS

DEPARTMENT OF REGISTRATION AND EDUCATION

M. F. WALSH, *Director*

BOARD OF

NATURAL RESOURCES AND CONSERVATION

STATE GEOLOGICAL SURVEY DIVISION

M. M. LEIGHTON, *Chief*

JEFFERSONS PRINTING & STATIONFRY CO
SPRINGFIELD, ILLINOIS
1931

Prefatory Note

The Illinois State Geological Survey celebrated the twenty-fifth anniversary of its founding on April 30th and May 1st, 1930. The papers presented at the two days' sessions include a historical survey of geological studies in the State both prior to and since the founding of the present organization, a survey of Illinois' coal industry and its needs, and regional studies of the conditions of accumulation of the Coal Measures strata, from Pennsylvania to Texas. The formal papers given at the meetings are here printed both as a part of the record of the Survey's work, and as valuable contributions to our coal industry and to research in Coal Measures stratigraphy.

The Illinois Coal Bureau generously shared in the cost of printing the articles under *"Research Needs of Illinois' Coal Industry,"* first printed as Cooperative Mining Series Bulletin 33, and here reprinted as Part III of the Proceedings.

CONTENTS

Illustrations

Page

TABLES

Part I

Dedication of the Quarter-Centennial Program to the Memory of

T. C. CHAMBERLIN, LL.D., D.Sc.

Vice-Chairman, Illinois State Geological Commission, 1905-1917
Geological Adviser, State Board of Natural Resources
and Conservation, 1917-1918

AND

R. D. SALISBURY, LL.D.

Geological Adviser, State Board of Natural Resources
and Conservation, 1918-1922

DEDICATION ADDRESS

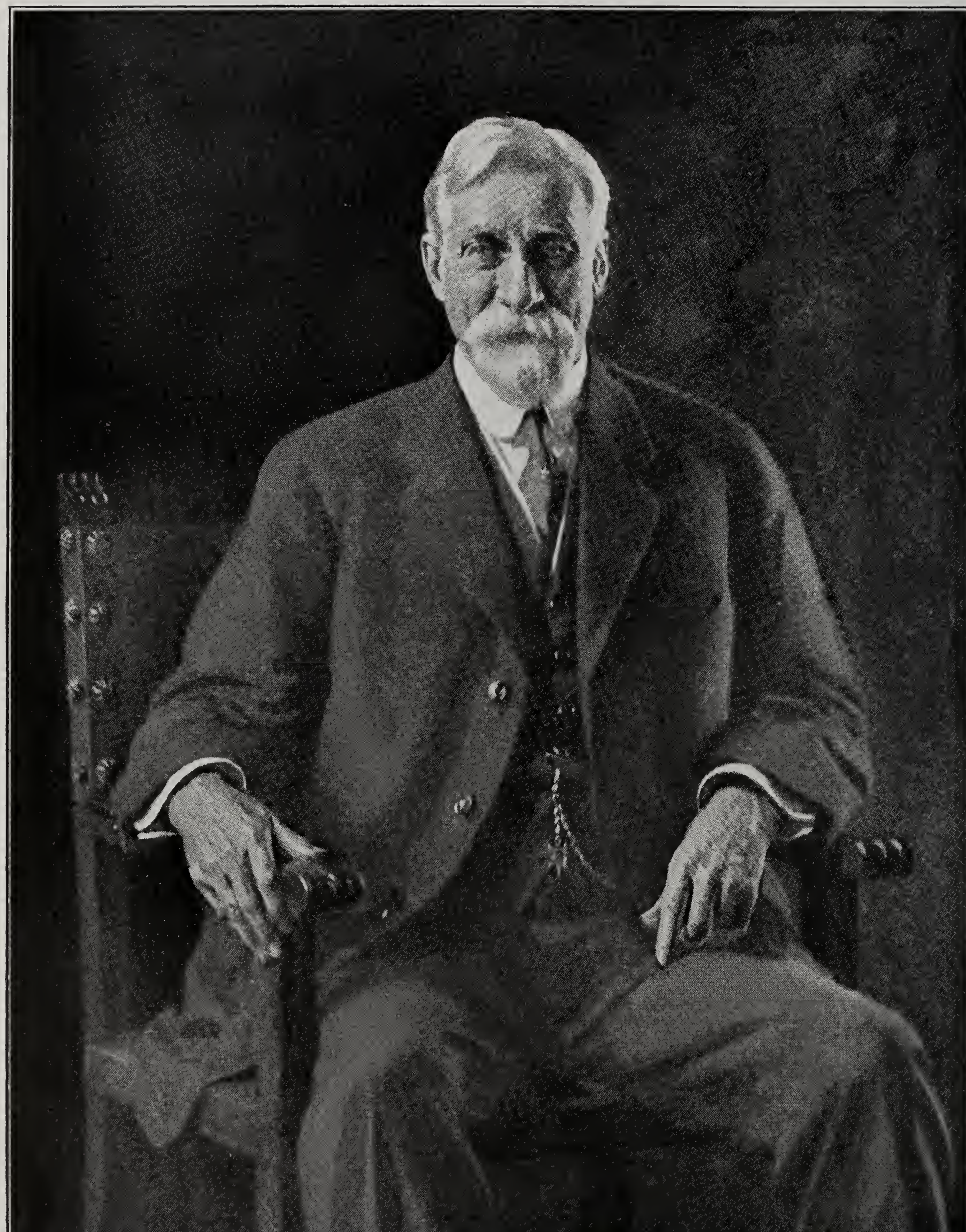
By Edson S. Bastin[1]

We have met here to celebrate the twenty-fifth birthday anniversary of the present Geological Survey of Illinois. Is there one of us who does not have some sentiment in his heart for birthdays? To the young they are radiant lights along the road of increasing strength and accomplishment; to the old they mark declining powers but increasingly rich stores of memories that come with growing wisdom and experience. Birthdays are dedicated by parents to their children, and by children, when they get farther along the road of life, to their parents. We, on this twenty-fifth anniversary of the establishment of the Illinois Geological Survey, may very appropriately dedicate this birthday to the two distinguished men, Thomas C. Chamberlin and Rollin D. Salisbury, who are mainly responsible for its founding and who stood towards it *in loco parentis.*

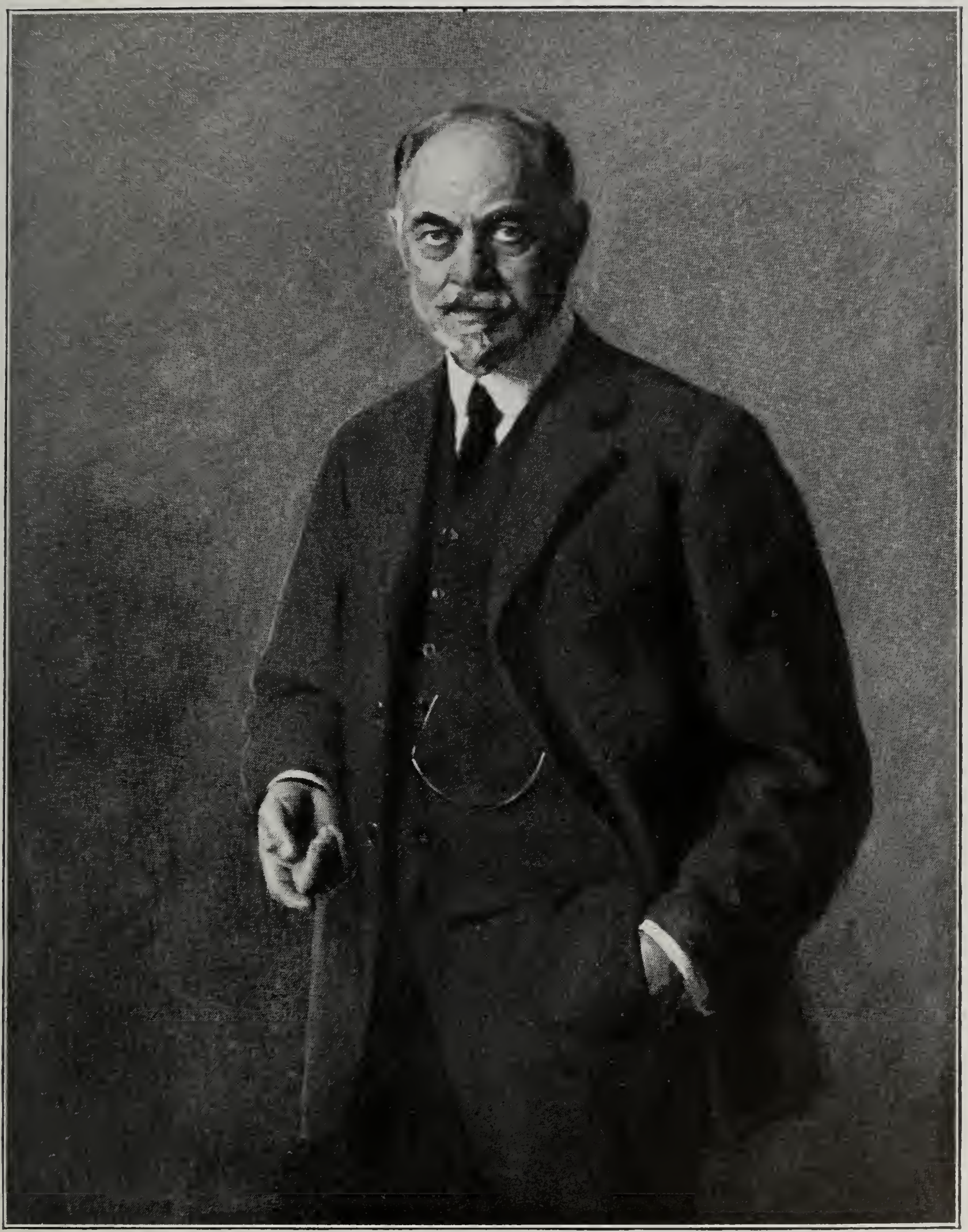
Let us turn our thoughts backwards then twenty-five years to learn something of the circumstances under which the Survey was founded. The present Survey was not the first Geological Survey of Illinois and we should be ungrateful indeed if we did not honor also on this occasion the work of the first Survey inaugurated in 1851 and carried on with distinction and with great usefulness, mainly under the leadership of Dr. A. H. Worthen, until 1872 when it was abolished. In 1877 it was given a feeble renewal of life as an adjunct to the State Museum of Natural History but was left without appropriations for real accomplishment, and after Worthen's death several of his successors were men without geologic training, a notable exception being William F. E. Gurley, veteran paleontologist, whose presence with us today in good health and perennially youthful spirit adds to the happiness of this occasion. I heard on good authority that one malicious young wag, a contemporary of Gurley's, used to pass a geologic map up-side-down to a certain state geologist of this period and that it was as acceptable in that attitude as in any other.

This was the pass to which geologic investigation in Illinois had come when in 1905 Thomas Chowder Chamberlin, head of the Department of Geology of the University of Chicago, and his associate, Professor Rollin D. Salisbury, became interested in the establishment of a new geological survey. Returning to his native state of Illinois after a rich experience as state geologist of Wisconsin and as president of the University of Wis-

[1] Geological Adviser, Board of Natural Resources and Conservation; Chairman, Department of Geology and Paleontology, University of Chicago.



Thomas Chrowder Chamberlin



Rollin D. Salisbury

consin, Professor Chamberlin understood fully the great service which geological studies, conducted on a high plane, could render in the development of the mineral resources of Illinois as well as in the general enrichment of the life of its people. With the aid of Professor Salisbury and of other associates he was successful in interesting Governor Deneen in the project and an act establishing the present Geological Survey was passed by the legislature and became operative on July 1, 1905. The Survey was placed under the guidance of a State Geological Commission whose chairman was Governor Charles S. Deneen; Vice-Chairman, Professor T. C. Chamberlin; and as a third member, former President E. J. James of the University of Illinois. And by this Commission the first director of the Survey, Dr. H. Foster Bain, was appointed in the fall of 1905.

Under these auspices the Survey operated until 1914 when, in a general reorganization of the educational agencies of the State, the Board of Conservation of Natural Resources was created and the Geological Survey as well as other scientific Surveys was placed under its jurisdiction. On this board Professor Chamberlin remained the geologic member until his retirement from active service in 1919 when, very appropriately, he was succeeded on the Board by Professor Salisbury who served until his death in 1922.

To the wise guidance of these distinguished men, given through a period of seventeen years without other reward than the satisfaction of useful achievement, and given unstintedly in the course of unusually busy lives, the State owes a debt of profound gratitude.

The Board of Conservation of Natural Resources, under which the Survey now operates, includes, as its Chairman the Honorable M. F. Walsh, Director of Registration and Education, Dean Charles M. Thompson, representative of the State University, Professors William A. Noyes and William Trelease of the University of Illinois, Professor Henry C. Cowles of the University of Chicago, and Mr. John W. Alvord of Chicago. The geologic work of the State owes no small measure of its success to the interest which these men who are not geologists have taken in it and to their fearless and unwavering adherence to the policy of selecting for the scientific work of the State men of the best professional qualifications wherever they might be found and to guiding such work along the lines of maximum usefulness to the people of the State. This has made possible the clean record of efficiency and public service not surpassed and rarely equaled even by organizations operating under the protection of a civil service system.

Part II

Historical Retrospect of Geological Investigations in Illinois and Their Relations to the State

Morning Session, April 30th

Dr. Edson S. Bastin, *Presiding*

INVESTIGATIONS PREVIOUS TO THE FOUNDING OF THE PRESENT STATE GEOLOGICAL SURVEY

By C. W. Rolfe[1]

The earliest recorded observation of geologic interest in Illinois seems to be the finding of coal along Illinois River by the French explorer, Father Hennepin, about 1680. During the next century and a half, numerous travelers and exploring parties crossed the State or worked within its borders, and in their reports mentioned a varied list of geological items which they had seen. A few studies and notes made by trained geologists and naturalists during the early part of the 19th century were included in reports which were later published. Among these might be mentioned a geological map of the country east of the Mississippi by William Maclure, who for many years was president of the Philadelphia Academy of Natural Sciences; some notes on the lead region of northwestern Illinois by H. R. Schoolcraft in 1818-19; some references by two military expeditions under the direction of Major Long, whose report was published in London in 1825; a cross-section through the Ozark region by G. W. Featherstonaugh in 1834; and a fairly detailed study of the lead region of northwestern Illinois by David Dale Owen, which was later revised by Whitney and by Weller.

The years between 1825 and 1850 were everywhere a period of considerable interest in the natural sciences. Many physicians, philosophers, writers, et cetera became also naturalists. The studies of European and American scholars in the new science of geology were becoming known and were eagerly followed by two groups of men—those who were always reaching out in quest of the unknown, and those who were beginning to sense the part which a knowledge of geology might play in economic life. A number of states organized surveys and did considerable work in determining the geology—particularly the paleontology—of their respective regions and in making geologic maps. Notable among these early efforts was that of New York, which under James Hall produced the most complete report made by any state. Massachusetts, under the leadership of Dr. Hitchcock of Amherst, also did good work. By 1850, twenty-one states had established geological surveys. Some of them were short-lived, but most of them were functioning in 1850. In addition, the United States Government Land Office had done

[1] Professor Emeritus of Geology, University of Illinois.

some geological work in Iowa, Wisconsin, and other states, using army officers to direct the work.

In 1848, largely under the stimulation of Louis Agassiz who had come to America two years earlier, there was formed the American Association for the Advancement of Science, which was destined to exert its influence in the founding of a number of new geological surveys. At its meeting in August, 1849, it received a communication from the Mississippi Association of Geology and Natural History, asking help in bringing about a geological survey of that state. In reply, a committee of fifteen was appointed to draft a memorial to be sent not only to the Mississippi legislature, but also to all states which did not at that time have active surveys, urging their establishment, or re-establishment, as the case might be.

Within a few months this memorial reached Governor French of Illinois. It pointed out that upon each state rested the responsibility of making its contribution to the complete geologic map of the country. It also stressed the real value of such surveys to agriculture, to railway engineering, to the users of stone materials, to the mining and metallurgical industries, to solving problems of water supply, and to the departments of geology in colleges which would benefit by the added teaching material thus made available. This memorial—a paper strongly written and convincing in its argument—was signed by such outstanding men as Professor Louis Agassiz, Professor W. B. Rogers of the University of Virginia, State Geologist H. D. Rogers of Pennsylvania, Professor Lewis Beck of Rutgers, Professor Joseph Henry of the Smithsonian Institute, and others.

It is not strange that with this paper before him, Governor French should have incorporated in his message to the legislature on January 7, 1851, a recommendation looking toward the establishment of a geological survey in Illinois. In conclusion he said, "We have unmistaken evidence that this state is scarcely excelled in the extent of her mineral riches, and all that seems wanting to render them richly productive is to point attention to them. As some considerable time will be required for a careful and minute geological survey of the whole state, I would respectfully suggest whether its importance would not justify a limited appropriation, to be followed by others thereafter, as the results and prospects of success might render desirable." At the same time, he sent to both the Senate and the House copies of the memorial from the American Association for the Advancement of Science. The Senate at once appointed a committee to look into the matter, and within three weeks, Mr. Wynn, Senator from Edgar, Coles, and Crawford Counties, reported a bill which was soon passed. This bill established a Survey, provided for the appointment of a geologist, and specified his duties.

Dr. J. G. Norwood, the first appointee, began his work in October, 1851, and was in charge of the Survey until the spring of 1858. The tangible results of his work were a paper published with Henry Pratten in the "Journal of Natural Sciences" of Philadelphia in 1855; a brochure published in 1857, consisting of less than 100 pages, largely coal analyses and unrelated sections, and containing a small geological map which was the first approximately accurate representation of the geologic formations in Illinois; some notes on the lead deposits of Hardin County which were later published in Volume I of the Worthen Survey; and a sheaf of field notes by his assistants.

In March, 1858, Norwood was succeeded by A. H. Worthen, and the Survey at once entered upon a new era—a period during which a prodigious amount of work was accomplished, whose results were published in eight large volumes which still hold a commanding place in the field of American geological literature.

Worthen was a man of ability, great energy, unbounded enthusiasm, and unusual vision. Born in Vermont, he came to Illinois in 1836, at the age of twenty-three, settled at Warsaw and engaged in merchandising. Almost at once he became interested in the geodes which were so abundant around Warsaw that they were used to macadamize the streets, and was led to believe that they had resulted from the solution of some sort of fossil. About this time Mantell's "Medals of Creation" and "Wonders of Geology" came into his hands. These volumes so stirred and interested him—opening up, as they did, a whole new world—that he began to spend a good deal of time searching for fossils. As his interest in geology increased, his business suffered and about 1852 he disposed of it in order to devote himself entirely to geology. His avocation had become his vocation.

He spent a short time as assistant to Dr. Norwood in Illinois, and then in 1855 went to the newly organized Iowa Survey, where he served under James Hall, who had done such notable work in New York. It was a great thing for Worthen to have come under the tutelage of Hall, whose influence was plainly evident later in the preparation of Worthen's reports on Illinois paleontology, which in excellence were second only to those of New York. During his connection with the Iowa Survey, Worthen spent considerable time investigating the strata outcropping along Mississippi River from southern Illinois northward.

Upon his return to Illinois in 1858 to take charge of the State Survey, Worthen was able, through his wide acquaintance, to command the services of a number of highly trained assistants. His own interest was primarily paleontological, and this placed him at a disadvantage for a time, because the demands of the legislature were for economic studies. It was only by the repeated assertion that paleontological studies were necessary as a foundation for economic studies, and finally by the intervention of a governor's veto, that the day was saved for the Survey. Funds were not appropriated for the publication of his earliest reports, and not until 1866—eight years after he began his work—did his first volume appear. This volume contained no paleontology, but Volume II, published in the same year, was devoted entirely to paleontology. Two other volumes, about half of which were county reports, followed in close succession. In 1872, Worthen was notified that no more field work could be done, but small appropriations for the preparation and printing of other volumes continued until 1875, when all provision for the Survey ended. By this time, reports for all of the counties except DeWitt had been published.

In 1877, a State Museum was established at Springfield, and Worthen was placed in charge as curator, remaining in that office until his death. This position gave him an opportunity to continue his studies of fossils and to prepare Volumes VII and VIII of his reports for publication. The speaker spent several days with him shortly before his death, and found his office stacked with trays of carboniferous fossils, on which he was working in preparation for a final discussion of the Coal Measures of the State. Death overtook him in 1888, before this work was finished.

During the period that Worthen was in charge of the Survey, he not only accumulated for the State a collection of fossils which ranked among the best to be found anywhere in this country, but also built up a private collection which rivalled that of the State. After his death, the Chicago World's Fair Commission purchased the private collection from his family, exhibited it with the State collection, and at the close of the Fair presented it to the University of Illinois.

Worthen's successor, Joshua Lindahl, professor of zoology in Augustana College, re-edited and added to Volume VIII of the Worthen Survey, which had not gone to the printer at the time of Worthen's death. He also prepared the geologic exhibit for the World's Fair and had charge of it until July.

In July of 1893, Mr. W. F. E. Gurley of Danville succeeded Lindahl as Curator of the State Museum, at once taking charge of the World's Fair exhibit. He held the position until 1897. Although a civil engineer by profession, Gurley had long been an enthusiastic paleontologist, and had accumulated a very valuable collection of Paleozoic fossils. In 1894 and 1895, he had published privately two small pamphlets describing new species of Carboniferous fossils, and he now saw an opportunity to continue with this work. He obtained appropriations from the legislature for publication, and in four years he issued, in collaboration with S. A. Miller, ten bulletins, illustrated with fifty-one plates of fossils, most of which described crinoids.

About 1895, Stuart Weller, who had just become a member of the geology faculty in the new University of Chicago, began a study of the Niagaran fossils of the Chicago region, and besides several short papers, he published a monograph on the Crinoidea in 1900. Later, he undertook a similar study of the Trilobita, which, however, was not published until 1907.

Early geologists had noted the unorganized deposits, which with their included boulders cover most of the surface of Illinois, and quite generally believed that they had been deposited by icebergs. Professor T. C. Chamberlin was one of the first to recognize the significance of glacial topography, and his investigations resulted in the discovery that drift sheets of several ages were present, and had been deposited by land ice. In 1883 he published a paper which included a map of the terminal moraines; and in 1886 he began under the auspices of the United States Geological Survey, detailed studies, assisted by R. D. Salisbury, Frank Leverett, and L. C. Wooster. These studies culminated in Leverett's great monograph of the Illinois Glacial Lobe in 1899.

During the same years, O. H. Hershey published a number of papers on independent Pleistocene investigations, chiefly in northwestern Illinois. Shortly before the close of the 19th century F. C. Baker began his studies of Pleistocene faunas. In 1902, George H. Ashley published an extensive report on the Eastern Interior Coal Field. In 1903, H. F. Bain made a survey of the fluorspar district in southern Illinois, and later examined the lead and zinc regions in the northwestern part of the State, and his reports were published by the United States Geological Survey in 1905.

The first area in Illinois to be mapped topographically by the United States Geological Survey was the East St. Louis quadrangle in 1888. Soon thereafter work was begun in the Chicago district, along the upper Illinois valley, and in the Savanna region.

In 1891, the World's Fair Commission invited the University of Illinois to prepare a relief map of the State, and this task was assigned to the speaker. It was understood that the work would have to be done by using a base formed from railroad profiles, supplemented with barometric levels run on the main highways and verified at all points where these crossed the railroads. Measures were taken to eliminate the natural barometric variations which occurred during each day's work, so that the readings would really represent changes in elevation. Each county was surveyed and mapped independently, and when the maps of contiguous counties were brought together, it was seldom that a difference of more than ten feet was found. From these county contour maps, copies of which are in the Survey files, a clay model of the State was made, and later reproduced as a plaster cast, which after the fair became the property of the State Museum. The county maps were used also in the construction of the relief maps of the State which are found in many of the University buildings.

In the meantime, the United States Geological Survey continued the detailed topographic mapping of quadrangles. By 1905 work had been completed on twenty-five quadrangles which were wholly or partly in Illinois. A number of these have since been resurveyed.

Detailed geologic mapping of Illinois areas was begun in 1896 by W. G. Alden, who surveyed the area included in the Chicago folio, published by the United States Geological Survey in 1902. In 1899, M. R. Campbell and Leverett mapped the Danville region and prepared the Danville folio, published in 1900; and in 1902 M. R. Fuller and G. H. Ashley mapped the Patoka quadrangle.

In 1894, the University of Illinois asked for an appropriation for equipping a laboratory for research work in coal mining and ceramics, and for the establishment of a geological survey. Shortly thereafter a change was made in the University administration and the new president, feeling that the sciences were absorbing too large a share of the support given to the University, asked that the bill be withdrawn, to be re-introduced at some later session. The opportune time did not come during his term of office. Before the bill was withdrawn the coal and clay interests of the State had prepared to give it enthusiastic support, and there is little doubt but that it could have been passed. Ten years later, under another University president, the same bill was again introduced, and again the coal and clay people stood behind it. A bill covering the establishment of a geologic survey was also introduced by the University of Chicago. Later, it was agreed that the University of Illinois bill should be divided, and that its three interests should come before the legislature separately. As a result, bills were passed for the establishment of departments of mining engineering and ceramics in the University of Illinois, and of the present Geological Survey.

EDITOR'S NOTE

Since the preparation of the foregoing paper, attention has been called to the record of a meeting of the Western Society of Engineers (Journal, Vol. 10, pp. 131-166, 1905), held on February 1, 1905, to consider the need for a Geological Survey of Illinois. The representation in addition to the membership included other engineers, mineral operators, University professors from the University of Illinois, University of Chicago, and Northwestern University, representatives of labor, state geologists from other states, and geologists from the U. S. Geological Survey.

A petition prepared at that time was adopted by the Board of Direction of the Society at a special meeting on February 11, 1905, and was sent to the Governor, to the officers and members of the General Assembly, to officers of the State Administration, and to prominent business men in the State.

THE INITIATION OF THE STATE GEOLOGICAL SURVEY

By H. Foster Bain[1]

Three remarkable men constituted the board that organized the State Geological Survey and directed its first steps. Thomas C. Chamberlin, Edmund J. James and Charles S. Deneen formed a trio in which vision, courage and ability were brought together to an unusual degree. Among geologists, Professor Chamberlin's name ranks always first; among University administrators, President James takes equally high rank; among political leaders of courage and vision the then Governor, now Senator, Deneen stands out equally. Fortunate indeed was the organization which had these men as friends and founders.

The decision to establish a survey was made and the definition of its field and scope determined before I was invited to participate. There had been a growing desire on the part of professional geologists such as Professors Chamberlin and Salisbury at Chicago, Professor U. S. Grant at Northwestern, Dr. J. A. Udden at Augustana and indeed all who had occasion to work in Illinois, that the State should again take leadership in the study of fundamental geology of its area and the application of the resulting knowledge to education and industry. Engineers, such as A. Bement and his associates in the Western Society of Engineers, and coal operators led by Francis Peabody, Carl Scholz and many others felt that the mineral industries of the State needed the foundation that only a well rounded out geological survey can give and believed, as has proved true in fact, that the consequent growth of the industries would repay many times the necessary expenditure of common funds for a common purpose. The University, alive then as now to its true place as the servant of the people in all that may be done in application of knowledge to the common good, realized the responsibility and the opportunity.

Charles S. Deneen had but come to the Governor's chair from the position of Prosecuting Attorney in Cook County. He was a lawyer by training and might have been expected to be concerned more with maintenance of the existing rights and status than of building that which was new, especially in engineering matters. A quarter of a century ago the engineer had not attained the position that he now occupies in the public councils, nor was it as widely recognized as at present that the wise conservation and use of the materials and forces of nature for the benefit of mankind is fundamental

[1] Director, Illinois State Geological Survey, 1905-1909. Secretary, American Institute of Mining and Metallurgical Engineers, New York.

to the maintenance and growth of civilization. As a nation we were still under the impress of the era of free land and unlimited mineral resources. It was then all the more remarkable that in the first year of his term the new Governor fought for and obtained the initiation of three engineering projects all looking toward the study and better use of the resources of the State. The Highway Commission, the Geological Survey, and the Internal Improvement Commission were agencies whose establishment testified to the vision and constructive leadership of the Governor and clearly evidenced the dawn of a new day. It is perhaps also worthy of note as indicating the spirit in which the tasks ahead were approached and the freedom from bias and narrow partisanship, that the men chosen as chief executives of the two first named were from outside the State and that two of the three engineers who formed the third commission were leading Democrats.

Under such happy auspices it was a pleasure to work and the interest taken by the Governor, President James and Profesor Chamberlin in the initiation of the survey never lagged. From first to last they were always ready for careful consideration of its problems, sound advice as to its conduct, and unwavering support of its policies.

On an occasion such as this, one may be forgiven if he be a bit personal and reminiscent. I was in the far west when a telegram reached me inviting me to meet the new commission to consider taking responsibility for direction of the survey. I came east at once and met the board at Springfield. Professor Chamberlin was an old friend and teacher. I had not previously met either President James or Governor Deneen though both were well known to me by reputation. It was a long time ago and when I was introduced to the Governor he said: "You are a much younger man than I thought." "Well Governor," I replied, "that is just what I was thinking of you," and with this breaking of the ice a friendship was formed that has, I am glad to say, survived the years between.

The commission was kind enough to elect me to the position of Director, fixing the salary at what was then considered the magnificent sum of $3500 per year. The Governor explained that he could not justify any larger sum since that was what the other state officers, including the Treasurer, got; a statement that later events proved might possibly have been subject to slight qualification since it is the income, not the salary, that counts.

President James took me to Urbana, which I then saw for the first time and introduced me to such of the officers and faculty of the University as were in residence in the summer. Among them was Professor Rolfe who had been active in the movement to establish the survey and whose then keenest interest was in the establishment of the work on ceramics provided for in the same bill. He kindly undertook direction of the whole of the studies on clay and a close integration was effected between the survey work on the occurrence and distribution of the raw materials and the University tests and studies of processes of utilization. Similar close relations were built up with the Engineering Experiment Station, then under the direction of Professor L. P. Breckenridge, familiarly and lovingly known then as now to a wide circle of friends as "Breck." Dr. Edward Bartow, then Director of the State Water Survey, was equally cooperative as were various other heads of departments, but memories cluster especially around the name of S. W. Parr. It was not only his wide knowledge of coal, his fertility in experimentation, his sound judgment, but his attractive character that made him a large factor in the new work. His generosity was shown in that, despite the chronically crowded condition of the University buildings, he cleared out one of the largest and best situated rooms in the Chemistry building and made it available to us. Later, from time to time as need arose, he gave us more and more space until I sometimes wondered if he recalled the fable of the camel's nose.

This generous cooperative attitude was characteristic of the whole University and later I found it equally evident in the welcome given us by the coal operators, the United Mine Workers, the Department of Mines at Springfield, the Director of the State Museum, the men in the various schools and Universities, and the citizens generally. The whole State was ripe for a new study of its resources.

After making preliminary arrangements for room and deciding other matters of the moment, I went west again to complete my work for the Government and did not return to Urbana until November when with wife, baby, and colored cook, and with household goods, alas, trailing far behind on slow freight, I moved to Urbana. Looking around now at this beautiful and well paved city it is hard to realize just how raw and ugly the place looked then in contrast with Washington. The November rains were on, the trees bare, the mud deep, and the hotel our only refuge. I never quite dared sympathize as fully as I would have liked with the other members of the family for fear tears would join the rain. For myself there was the interest of working out plans, of gathering a staff and of organizing the work but probably if justice were equal there would be more monuments in this world to the foremothers and less said about the hardships met by the forefathers.

Our own hardships were temporary and mental. With the warm hospitality and wide welcome established we were quickly picked up and made a part of the throbbing intellectual and social life of the University and so given three of the happiest years of our lives.

In organization of the Survey it was decided to make it as far as possible serve both educational and economic needs and it was further agreed that the latter should not be interpreted narrowly. Accordingly, a special series of Educational Bulletins was projected designed to place at the service of the teachers of the State the local material suitable for use in the class room. Professor Salisbury undertook this as his especial responsibility and a most useful series of reports has since been published. Topographic mapping was recognized as a basic necessity and a cooperative agreement made with the U. S. Geological Survey which, I believe, is still maintained and which is giving to the State an excellent base map for all engineering and scientific purposes. Later, in cooperation with the Internal Improvement Commission and the Department of Agriculture, large scale detailed maps of certain river basins were made for purposes of planning reclamation and drainage. Dr. Grant made for us a large scale map of the part of the lead and zinc fields in this State corresponding to those he had previously completed in Wisconsin. Dr. I. Bowman, now the well-known Director of the American Geographical Society, made an intensive study of a new type of the water resources of the East St. Louis field. Weller, Savage, Ulrich and others were set to work on studies of the paleontology and stratigraphy from which we now derive scientific and material benefit. It would require more time than is available to mention all or even most of the men who contributed to the early work of the Survey. Instead I may call attention to three general trends set into motion.

It had already become the habit of State Geologists to look to the U. S. Geological Survey for expert assistance and to enter into cooperative agreements with it where each party supplemented the funds and knowledge of the other. An arrangement of this nature was early effected applying particularly to the study of the coal fields. Under it the wide knowledge in particular of Dr. David White was brought to apply on local stratigraphic problems, and under it also Mr. Frank DeWolf was detailed to work in Illinois. Having got him out here we never let him get back. He became in time Assistant Director and when I again went west I was most happy to see him succeed to my position.

There had long been a feeling of uneasiness among geologists not connected with the Federal Government over the very general spread of influence of the U. S. Geological Survey. It was questioned whether so much centralization might not lead even among the best of men, a position we geologists gladly concede to ourselves, to a condition under which there would not always be that independent thinking and criticism that is necessary to progress in science. Accordingly we looked around for some means of developing in the staffs of the State Surveys experts equal to those of the Federal Survey. As a first step the Mississippi Valley Association of State Geologists was organized at the old Quadrangle Club in Chicago. After a few years it was merged into the now well established State Geologists Association. The policy was built up of exchange of men as well as of data and so when petroleum was found in Illinois, instead of attempting to study the fields ourselves we called in State Geologist W. S. Blatchley of Indiana, already a well known authority. He was later succeeded by his son Ray Blatchley who spent a number of years following developments in this and neighboring states. Other exchanges were made and today, in part as a result of this policy but mainly perhaps because of growth in resources, the experts of the State Surveys rank equally with those of the Federal Government and a well balanced opinion is maintained.

Another trend of historic interest was toward study of the technical and economic phases of the mineral industry as well as those more directly geological. Although this was not new the Survey may properly claim credit for giving it great impetus. The coal industry was growing rapidly and many problems lay at hand. In cooperation with the Engineering Experiment Station, the U. S. Geological Survey and later the Bureau of Mines, the Department of Mines at Springfield, the various coal companies and the coal miners, many interesting technologic studies were undertaken. Dr. J. J. Rutledge, now Chief of the Department of Mines of Maryland, and Tom Moses, now president of the Frick Coal Company of the U. S. Steel Corporation, were among those who spent long days sampling the coal beds for the Survey. W. L. Abbott, on behalf of the Commonwealth Edison Company, cheerfully buried thermometers in huge coal piles that we might study spontaneous combustion and weathering. J. A. Holmes and the pioneers in the safety work of the Bureau of Mines gave us their counsel and established here at the University the first Mine Rescue Training Station outside Pittsburgh. The opening of this station was the outgrowth of a very interesting Fuels Conference held at the University in which many took part. It was as a direct result of resolutions passed at that Conference that the Mining Department of the University was founded and another work initiated which I regret to say has not survived; I refer to the Miners Institute which always seemed to me to be pregnant of much good to the industry. But I have already taken more time than may be allowed. I would gladly refer to the many others, the always kindly and helpful Senator McKinley, the outwardly harsh but inwardly comprehending Uncle Joe Cannon, Senator Dunlap who long represented this district at Springfield, G. W. Traer and other far seeing coal operators, John Walker then president and W. D. Ryan then Secretary of the United Mine Workers of Illinois and all the men and women who served on the staff or in consulting capacity. Looking back at those years I remember only friendly faces and willing hands. The universal cooperative spirit, the general desire to help are the things most deeply etched in memory and I shall always be thankful to have had the privilege of a small part in the making of the new day then just dawning.

THE STATE GEOLOGICAL SURVEY DURING THE PERIOD 1909-1923

By F. W. DeWolf[1]

INTRODUCTION

When Dr. H. Foster Bain withdrew from the direction of the Survey in 1909, he had in a few short years given it a wise course which it was bound to follow. He had also established good relations with State officials and prominent members of the legislature, with leaders of our educational institutions and technical societies, and with the forward-looking and responsible men in the mining and mineral industries of Illinois. I inherited this happy set of circumstances, and during my entire administration enjoyed their benefits.

I consider it altogether a fortunate situation, first, that the Survey was located at the University, where scientists and technicians and laboratories were available to assist in our work and the atmosphere was truly scientific; and, second, that the Survey functioned under a State Board of Commissioners or Advisers and had independent appropriations. This favored contacts with other universities of the State and also kept the Survey from becoming overly academic. The University provided larger quarters as they were needed; moving us from inadequate space in the Chemistry building to a fine suite of rooms in the new Natural History building, and finally into the commodious and convenient space in the Ceramics building.

The membership of the State Geological Commission and its successor, the Board of Natural History Advisers, was most favorable. I found Governors Deneen, Dunne, Lowden, and Small, without exception, interested in the progress of the Survey's work, and each of them was responsible for some improvement of our conditions during his administration. Similarly, President James, President Kinley, and Deans Babcock and Thompson, who appeared later on the Board of Advisers, were seriously interested in our work and our welfare. The advice of Professor S. A. Forbes on various matters I greatly appreciated. On the technical side, the Survey was fortunate in having on the Board, in succession, eminent geologists T. C. Chamberlin, R. D. Salisbury, and E. S. Bastin.

REVIEW OF SURVEY WORK

The work of the Survey seems to me in restrospect to be of two kinds, though they dovetail in a manner that makes separation impracticable as well

[1] Director, Illinois State Geological Survey, 1909-1917; Chief, 1917-1923. Vice-president, Louisiana Land and Exploration Company.

as unwise on an occasion like this. The bulk of the work was the routine finding, recording, and mapping of facts. This in itself is not science, though it is prerequisite to geological science. The other phase of the work, of course, was interpretation by analysis, comparison, and deduction, which is in truth scientific. Oddly enough, the deductions, which require the greater skill and capacity, and represent the flower of the work, are more likely to be found wrong eventually, while the same facts remain to be considered by the next interpreter.

It would be impossible for me briefly to separate the work done by the Survey during fourteen years into these two kinds, or to relate the changes in interpretations that have already been made, or the progressive increase of knowledge which seems true and final. I fear that I can only cover the work in a general way and indicate its distribution and quantity rather than quality, under a series of somewhat disconnected headings.

Topographic Mapping

The preparation of a topographic map of Illinois in quadrangle units was started by the U. S. Geological Survey prior to the organization of the State Survey in 1905, and thereafter was continued in cooperation. When I took charge of the Survey in 1909 about 14 per cent of the State had been mapped. During my administration about 14,000 square miles or 25 per cent of the State was added, bringing the total in 1923 to 39.4 per cent. During this period about 5,500 miles of primary levels and 5,000 miles of primary traverse were run, and more than 2,000 permanent bench marks were installed.

This work included, besides quadrangle surveys, the mapping of many stream valleys as a basis for reclamation studies, and of many hundred miles of strip area, at the request of State Highway officials, for use in planning the location and construction of state roads. All such surveys were to be incorporated in quadrangle units later. It was my further plan to group quadrangles into county-unit maps, and eight or more such maps were published during my term of service.

The rate of mapping increased greatly in 1921, due to growing appreciation of the usefulness of the maps for various public purposes, including road building, land drainage, and public water supply. I understand the present rate of progress is still greater, and I feel sure that the rapid completion of the map of the State is a splendid public investment.

Very cordial relations existed with officials and employes of the U. S. Geological Survey, and particularly with Major W. H. Herron, who was in charge of Illinois work until his sudden death in the autumn of 1929. As a native Illinoian he was extremely interested in the rapid progress of the surveys, and his help and advice in the work was most important.

Plans for Drainage Reclamation

Closely related to topographic mapping was the Survey's drainage investigation program. In the early days a State Committee on Waterways Reclamation was organized to include joint work on this problem by the Internal Improvement Commission, the Geological Survey, and the Drainage Division of the U. S. Department of Agriculture. Later the work continued between the Survey and the Rivers and Lakes Commission. In 1910 we began large-scale surveys of the valleys of the Embarrass River and of Spoon River, and made gradient profiles of the Kaskaskia and the Big Muddy. In 1915 we made surveys of the Pecatonica. All of this work was in cooperation with the U. S. Geological Survey, which made substantial contributions to the cost.

Besides making surveys, we engaged the Harman Engineering Company of Peoria to prepare plans for reclamation, and we published the reports and maps for the Embarrass and the Spoon valleys.

Following this, we engaged G. W. Pickels, Civil Engineer at the University, and F. B. Leonard, Jr., practicing attorney, and supported a broad investigation of the engineering and legal aspects of drainage in Illinois. The results were published in 1921, with recommendations for revision of the State laws relating to drainage. This report was a comprehensive one, and attracted state-wide interest.

Detailed Geological Surveys with Topographic Base

Early arrangements had been made by Director Bain with the U. S. Geological Survey for cooperation in geological mapping of the State as topographic maps became available. Several quadrangle bulletins and folios had been prepared prior to 1909. Following this period, and until 1923, some 35 quadrangle areas, covering 8,000 square miles, or 14 per cent of the State were surveyed. The work was representative of all parts of the State, and of all the geologic formations. We were fortunate in having expert consulting men in parts of this work, including Professors Salisbury and Grant of the State organization, and Messrs. David White, W. C. Alden, and Frank Leverett of the U. S. Geological Survey. The workers themselves were for the most part men of expert knowledge and long experience. Those of the Federal Bureau included E. W. Shaw, Henry Hinds, Wallace Lee, and Charles Butts. The more responsible men of the State staff were T. E. Savage, Stuart Weller, G. H. Cady, A. C. Trowbridge, R. S. Blatchley, John L. Rich, J. A. Udden, M. L. Nebel, H. E. Culver, J H. Bretz, D. J. Fisher, Frank Krey, J. E. Lamar, and R. S. Knappen. The most unified and consecutive work of this kind was that of Professor Stuart Weller on the Mississippian formations, extending from St. Louis to the southeast corner of Illinois.

Investigations of Illinois Coal Resources and of the Mining Districts

As the "Coal Measures" cover about three-fourths of Illinois, and coal constitutes by far the most important mineral resource, the study of the geology of the coals was naturally emphasized from the beginning of the State Survey. I came to the work in 1906 for detailed surveys in southern Illinois under the direction of George H. Ashley of the U. S. Geological Survey, and later, as assistant State Geologist under Dr. Bain, had supervision over several field parties engaged in state-wide investigations. Throughout my connection with the Survey the progress of our knowledge of the geology of the coal fields was of greatest interest to me. I believe no systematic work had been done to correlate Illinois coals with those of the standard section in the east until the visit of Mr. David White, of the U. S. Geological Survey, in 1907 or 1908. His comparison of fossil plants with those of type localities served to establish the presence and the approximate top of the Pottsville formation in southern Illinois, as well as to determine that the widespread coal No. 6 is at or near the horizon of the Freeport coals of Pennsylvania, which lies near the top of the Allegheny formation. Thus, the Illinois section was approximately correlated with that of the East.

But this work and all other varieties of coal investigations were outlined under Dr. Bains' administration. During my period the problem was largely to extend in larger quantity and more broadly the routine collection and study of innumerable drill records from the mining companies, and to map the extent of the coal beds and their structural features. In this early work the State men engaged included G. H. Cady, T. E. Savage, J. A. Udden, Jon Udden, and E. F. Lines. Federal men assigned to cooperate with us under supervision of George H. Ashley, and, later of David White, included E. W. Shaw, Henry Hinds, and Wallace Lee. During this period the assistance of Mr. A. Bement, Consulting Engineer, of Chicago was particularly helpful.

A second period began with the establishment of the Illinois Mining Investigation, under a cooperative agreement with the Department of Mining Engineering of the University and the U. S. Bureau of Mines. The legislature made special appropriations for work of the State agencies, and the Federal Department made substantial allotments. As a result, a group of geologists, mining engineers, and chemists carried on a systematic investigation which lasted ten years to my knowledge, and resulted in many fine researches and publications. This work was based on topographic maps where possible but could not await their slow progress, and therefore land maps were compiled for the entire coal field in various units. The results included an inventory of coal resources, studies of mining practices with especial reference to safety and efficiency, and determination of chemical and physical characteristics as affecting usability of Illinois coal for ordinary purposes, and for coking and for gas manufacture. During this period there was splendid cooperation with University representatives, including Professor Stoek of the Department of Mining Engineering, Professor Parr of the Department of Applied Chemistry, and Dean Richards of the Engineering Experiment Station, as well as with Joseph A. Holmes and Van H. Manning, directors of the U. S. Bureau of Mines, and with officers and inspectors of the State Mining Department. The notable series of publications included 17 bulletins by the Survey, 15 by the Engineering Experiment Station, and 9 bulletins and 7 technical papers by the U. S. Bureau of Mines. The Survey employees chiefly engaged in this work were F. H. Kay, assistant State Geologist, in charge; K. D. White, G. H. Cady, geologists; L. E. Young, mining engineer; J. M. Lindgren, chemist; W. A. Dunkley, chemist and gas engineer. In all of the Survey's coal investigations we had the support and cooperation of the officers and members of the coal operators' associations, and of the mining engineers and of fuel and gas experts in company employ. I feel that the contribution to the knowledge of Illinois coals, to their safe and effective mining and preparation, and their improved utilization was of large industrial importance to the State.

Oil Investigations

Oil production in Illinois which became important with the opening of the Casey field in 1904 reached an annual output exceeding 33,000,000 barrels in 1908, and a second peak of nearly equal height in 1910. Since that time the production has declined more or less regularly.

The Survey was engaged from the beginning in studies of the geology of the oil fields, and in efforts to find promising localities where additional fields might be developed. It was clear that the main field was located along a probable extension of the LaSalle anticlinal fold but, due to the lack of surface exposure of rock formations, the structural and stratigraphic relationships could be determined only by collection and study of well cuttings and innumerable drill records. Similar conditions existed over much of the coal field area, where the study of diamond-drill logs might indicate the presence of rock folds or terraces suitable for oil accumulation. However, in many counties of western and southern Illinois, where formations are more generally exposed, it became possible to carry on instrumental surveys in search of oil structures.

In 1909, R. S. Blatchley and assistants determined elevations for more than 1500 wells in Lawrence County, and collected records from all over the State. The study of these and of other logs collected by other men engaged in coal investigations resulted in Blatchley's first report published in 1910. This included a number of cross-sections of the subsurface of the State, revealing the general character of the Illinois basin, and the existence of minor folds and terraces where drilling would be justified. The report suggested the reason for and probable extent of the Sandoval or Centralia field which was discovered at that time, and also the Carlyle field, which was discovered later.

This timely and useful report was used by operators in the extensive drilling campaign of the next few years.

Mr. Blatchley's report on the fields of Crawford and Lawrence counties was prepared between 1910 and 1913 and was published in 1914. It contained a very large collection of logs and was profusely illustrated with maps which were greatly appreciated by the oil companies. Meanwhile, and following this date, various geologists engaged in specific areas prepared special reports on oil possibilities. A publication in 1912 contained papers by E. W. Shaw, of the U. S. Geological Survey, on the Carlyle field and a large area in southwestern Illinois, and one by F. H. Kay on the Carlinville oil and gas field. A report in 1913 by Henry Hinds, of the U. S. Geological Survey, included reference to the dome on which the Colmar or Plymouth oil field was developed. The report was delayed in publication but an extract from it appeared about coincident with the oil discovery in 1914. A report in 1914 by Blatchley covered Bond, Montgomery, and Macoupin counties. This was followed by a report by Wallace Lee of the U. S. Geological Survey, which pointed out the existence of the Staunton dome and other small structures in Macoupin County, where gas or oil were found in 1915. Following this, and to the spring of 1923, intensive work was done and reports were published by W. C. Morse, T. E. Savage, F. H. Kay, John L. Rich, Stuart Weller, A. D. Brokaw, Stuart St. Clair, M. L. Nebel, H. N. Coryell, L. A. Mylius, D. M. Collingwood, and by Charles Butts of the U. S. Geological Survey. These papers called attention to structures of possible importance. The principal work by Mylius and Collingwood related to the north end of the main oil field and its possible extension in area and to deeper horizons. It was published under the supervision of Dr. Leighton. Dr. James H. Hance, assistant State Geologist then took up detailed work in the old Robinson field, but his results were not ready for publication at the close of my administration.

Mention should be made also of technologic studies and demonstrations carried on in 1918 by Fred Tough of the U. S. Bureau of Mines in collaboration with T. E. Savage, and M. L. Nebel, and S. W. Williston of the State Survey, to develop a method of controlling water in the Flat Rock oil fields. The results were satisfactory, and suggested that large saving of money could be made by cementing off bottom water, thereby reducing the amount of water which had to be handled and also checking the decline of oil production. The operators welcomed this demonstration, and adopted the methods for gradual introduction.

In this connection I desire to acknowledge the splendid and full cooperation of oil company officials with the Geological Survey during the many years of my service here. I believe that they, and indirectly the State, profited from the work, which at all times was a substantial part of the Survey program.

Stratigraphic Studies

Reference has been made to the scarcity of rock outcrops in much of Illinois and to the need of studying drill records in connection with investigations of mineral resources. Of course, this is true also in a study of the sequence and the characteristics of the formations from a historical view point. The collection of records has been grist for the mill, to be supplemented where possible by observation of outcropping rocks and collection of fossils. A number of the Survey men have always been more interested in "pure" geology than in its economic features, and their work has resulted in important geological contributions. J. A. Udden, T. E. Savage, Stuart Weller, and C. B. Anderson made notable contributions as a result of studying well cuttings and logs. Notable stratigraphic work was done by investigation of outcrops by T. E. Savage, for the Devonian and pre-Devonian formations, and by Stuart Weller for the Mississippian formations. J. A. Udden, David White, T. E. Savage, G. H. Cady and H. E. Culver did most important work in the Pennsylvanian formations, while Udden, Savage, Shaw, and Leighton contributed largely to solutions of the Pleistocene problems. I am glad to record these impressions but at the same time to emphasize the fact that the entire staff made important contributions to the knowledge of Illinois stratigraphy. The publications are full of their results. Among these men just mentioned there were many trail blazers, and it would be an unjust estimate not to recognize the permanent value of much of their work. There was helpful cooperation with adjoining states, especially Missouri and Kentucky, and with the U. S. Geological Survey.

Lead, Zinc, and Fluorspar Investigations

Considerable importance attaches to the lead and zinc district of northwestern Illinois, and to the deposits of fluorspar, lead, and zinc of the southeastern counties of Pope and Hardin. In these areas Dr. U. S. Grant of Northwestern University supervised the Survey work, G. H. Cox studied the northern ore deposits and published a report in 1915. From 1917 to 1919 L. W. Currier studied the southern district, under the direction of J. E. Pogue, and prepared suitable chapters for the report on the geology of Hardin County.

Studies of Water Supplies

Although other State agencies were engaged in studies of water supplies for drinking and for industrial use, there was a geological aspect of this work which permitted the Survey to cooperate from time to time. One bulletin on surface waters was published in 1910 by the U. S. Geological Survey in cooperation with the State Water Survey, and with our organization. Later J. A. Udden gave much time to the study of water supply formations of northern Illinois. Our most elaborate report was one of artesian water in northeastern Illinois by C. B. Anderson, in cooperation with the State Water Survey, which made mineral and boiler analyses of the samples and otherwise shared the work, and informally with the Wisconsin Survey. The best of relations existed with Edward Bartow, H. C. Habermeyer, and A. M. Buswell who were from time to time in charge of the State Water Survey.

Investigations of Structural Materials

The importance to modern industry of raw materials for various kinds of structural products was emphasized in the work of the Survey from the beginning. Dr. Bain may have made reference to the early development of the Ceramics Department, and to the cooperation with the materials-testing laboratory at the University. Following the early work on fireclays and paving-brick clays, under the guidance of Professors C. W. Rolfe, I. O. Baker, A. N. Talbot, S. W. Parr, largely performed by Ross C. Purdy and A. V. Bleininger, on samples collected by geologists of the Survey, such investigations were continued from time to time. During my administration a large volume of field and laboratory work was done on fireclays, brick clay, sand-lime brick, Portland cement materials, limestone, sand and gravel for use as aggregate, and on molding sand. One large undertaking was the collection of aggregate materials on a state-wide basis for tests made by the Springfield laboratory of the Highway Department. Another was the sampling of roof and floor materials at 100 typical coal mines. The clay testing work for the Survey at the University was later directed by R. T. Stull, C. W. Parmelee, and R. K. Hursh, to whom I always felt greatly indebted.

Educational Bulletins

As an aid to teachers in planning field trips with students, the Survey continued to prepare and publish bulletins interpreting the physiography and geology of selected areas. This work was directed by R. D. Salisbury, of the University of Chicago. In 1909-1910 we published three of these bulletins which had been prepared during Dr. Bain's administration. During the following years bulletins were published covering the Middle Illinois Valley, the Upper Illinois Valley, the Wheaton Area, and the Galena-Elizabeth quadrangles. We also cooperated with the Chicago Geographic Society in preparing a report on the Starved Rock State Park. During the war period, a bulletin descriptive of the region around Camp Grant was prepared at the suggestion of the Army, as an aid in instructing officers to read maps and to understand the military significance of topography, rock formations, and ground water, in trench construction and related matters.

These various bulletins were prepared almost wholly by experienced teachers, including H. H. Barrows, A. C. Trowbridge, C. O. Sauer, G. H. Cady, and B. H. Schockel, and in one of them E. W. Shaw, of the U. S. Geological Survey, was joint author.

CONCLUSION

This completes a review of the subject allotted to me, and I am afraid that it has been dry and uninteresting to you. However it has been a pleasure to me to examine during recent days the formidable row of Survey reports in my library. Of course, this has called to mind many incidents and events, and the faces of old associates, many of whom unfortunately have already passed on. Nor am I unmindful of the high value of the services of those in the Survey who were engaged in office work, and whose names have not been mentioned in my review. The care of technical files, the editing, the handling of accounts and correspondence provided work of an exacting character which was handled by intelligent and faithful associates, most of whom were women. I desire to mention on the technical side Mrs. Helen Skewes Plummer, Mrs. Nellie Barrett Rich and Mrs. Henrietta Christensen Burgess; on the clerical side, Miss Carrie H. Thory, Mrs. Faith Neighbour Thory, and Miss Emma J. Nyberg.

It was a pleasure to me that the direction of the Survey passed on to Dr. M. M. Leighton, who was quite familiar with the organization, from long connection with it. I dare say that the plans of work have been materially improved. It is proper that the balance of work should change from time to time as between that of economic, professional, and cultural importance. There will always be need to serve the mineral industries and the engineering professions having to do with the surface and the subsurface geology. There will always be need to contribute to the knowledge of the geological history of Illinois and of the whole earth. The educational and cultural value of geology as a study in elementary and higher institutions should always be encouraged. However, economic pressure will change from time to time. At present Illinois and the nation still have the problem of terrific waste of coal in the ground, and of other mineral industries which are sick because of lack of efficient and economic organization on a national scale, with logical freight rates and market zones.

While such complicated problems will tax the best minds of the nation such Surveys as this can help at least in gathering some of the facts on which remedies must be based.

THE STATE GEOLOGICAL SURVEY DURING THE PERIOD 1923-1930

By M. M. Leighton

INTRODUCTION

Illinois is one of the Union's leading mineral states. This fact called our Geological Survey into being as a research bureau to provide fundamental information that was not otherwise available to the State's mineral industries and to the public. The State has within its borders large resources of fuel for heat and power, a wide variety of materials for construction purposes, fluxes for smelting ores, molding sand for foundries, and various kinds of mineral substances for abrasives, glazes, glasses, and absorbents—these in the form of coal, oil and gas, limestone, sand and gravel, cement-making materials, ceramic clays, shales, high-grade sandstones, fluorspar, silica, fullers' earth and other materials. The practically inexhaustible supplies of most of these are major factors in insuring the State's continued industrial development.

From time to time, the discovery of new uses for minerals vitally influences the trend of the different mineral industries, and changes in transportation facilities, such as the opening of the new Illinois Waterway, give opportunity for further development of the State's mineral resources. Therefore, from several standpoints there is great need for a continuing program of research studies.

The Geological Survey has carried on its work according to a carefully planned program. Sound principles directed the activities of the Survey in the beginning, and changing conditions have been watched in order that the work of the Survey might be kept in step with new needs and new technique, in accordance with these principles. The names of Thomas Chrowder Chamberlin and Rollin D. Salisbury are now in history as wise counsellors of the Survey, and the names of H. Foster Bain and Frank W. DeWolf, the two past directors, as administrators and molders of the Survey's policies and traditions. There have also been other valuable contributors from the industries and from the nation's scientists whose advice and services have been most helpful.

I became aware of the character of the Survey's policies while a member of the staff under Mr. DeWolf, and had admired the rational principles that gave vigor to the activities of the Survey, long before my services were commanded as Chief. Dr. E. S. Bastin had been called to succeed Professor

R. D. Salisbury as a member of the Advisory Board shortly before Mr. DeWolf's resignation, and it has been my observation, through seven years of close relationship, that the welfare of the Survey is receiving the same devotion from him that it did from his predecessor—a devotion that has a wealth of training and experience, as well as integrity and sound judgment, to draw upon.

GROWTH OF THE SURVEY

The Survey has grown steadily from the very beginning. The history of the Survey from 1905 to 1923 has already been covered. During the period 1923-1930, appropriations have increased with each biennium, as shown by the following table, indicating the Legislature's good will and the Governor's desire to see the Survey meet the growing demand for its services:

1921-1923	$203,865.00
1923-1925	226,470.00
1925-1927	234,220.00
1927-1929	250,720.00
1929-1931	316,310.00

The total increase for the period has amounted to more than $112,000.00. The Survey's continued welfare has been due to splendid co-operation all along the line and to the Survey's policies of rendering helpful service wherever possible.

With the increased demand for detailed data, there has come the need for specialization in the different lines of Survey activities. Sections for the study of coal, and for the study of oil and gas had been organized by my predecessor, and since 1923 it has been desirable to organize additional sections covering non-fuel products, engineering geology, subsurface studies, paleontology and stratigraphy, and educational extension. It is now possible to serve the industrial and public needs with information obtained by specialists who are devoting their full time to these different lines of study.

Studies in Coal

Studies in coal have included the preparation of the report on the coal resources of District III (western Illinois), by Dr. Harold E. Culver; a survey and report on coal stripping possibilities in Illinois, also by Dr. Culver; a more detailed report on the coal stripping possibilities in southern and southwestern Illinois, by Dr. Gilbert H. Cady; and one on coal stripping possibilities in Saline and Gallatin counties, near Equality, by Mr. Lloyd G. Henbest. Correlation studies by Dr. Culver were carried on in western and southwestern Illinois during 1923 and 1924, structural studies of the coal in the Duquoin area by Dr. D. J. Fisher in 1923, structural studies of the Coal Measures in the Galatia-West Frankfort area by Dr. Cady in 1924, the preparation of an educational bulletin on the occurrence, production, and preparation of Illinois coal by Mr. A. Bement, and the preparation of a comprehensive report on the coal resources of the State, following the completion of the various district reports. This report by Dr. Cady will comprise several volumes and will cover the geography, stratigraphy, lithology, structure, chemistry, mining conditions, and utilization of coal, and in addition will suggest future lines of research that should lead to a better understanding of coal and to new uses. Microscopic studies of Illinois coal and other studies of its constituents have recently been started, in order to provide a fundamental basis for studies along new or improved lines of utilization.

Studies in Oil and Gas

Studies in oil and gas have been made in various parts of the State, including the Alexis, Galesburg, and Payson areas, the Media anticline in Henderson County, the Jacksonville and Decatur areas, Scott and Greene Counties, the Centralia area, Central Pike County, the Sorento dome and Ayers anticline (portions of Bond, Madison, and Montgomery counties), the Sparta, Ava-Campbell Hill and Dupo areas, structures in St. Clair and Monroe counties, the Allendale fields, eastern Clark County and western Lawrence County. The results of most of these studies have been published with the exception of western Lawrence County and northern Crawford County reports, which are approaching completion. A library of nearly 300 analyses of oilfield waters from various horizons in different parts of the State has been obtained with the co-operation of the State Water Survey, and some progress has been made in a geo-chemical study of these analyses. Considerable study has also been given to the structural relations between the Pennsylvanian and the older formations and a report has been published on the carbon ratios of coal and their possible significance. A report has been issued on proper testing for oil structures in Illinois. A volume is now being written on stratigraphy and structure and the oil and gas possibilities of the State. Some attention has been given to petroleum engineering, including a study of corrosion in the eastern oilfields and a preliminary study of the oilfield sands in the Siggins Pool with a view to obtaining basic data for considering the possibilities of oil mining. Studies are in progress on oilfield muds and the effects of different types of oilfield waters on the setting of neat cement.

During the period, two new oil pools have been discovered, one north of Allendale in Wabash County, and one at Dupo in St. Clair County. In the first area prospecting had been specifically recommended by the Survey, and in the second the discovery of oil was made by the Ohio Oil Company on the northwestward extension of the Waterloo anticline, which had been mapped by this Survey.

In January, 1928, fire destroyed the offices of the Ohio Oil Company and most of their geological records and well logs. These were replaced from the files of the Geological Survey.

During the past year, geophysical studies have been inaugurated and the usefulness of the magnetometer for determining geological structures is now being tested on some of the well known structures of the State.

A number of geologists have carried on these various assignments, but most of the responsibility has rested upon D. M. Collingwood, Gail F. Moulton, A. H. Bell, and J. E. Lamar. Others include J. H. Hance, J. Marvin Weller, D. J. Fisher, Harold R. Wanless, R. S. Poor, Ben B. Cox, and T. B. Root.

Studies in Non-Fuel Products

The Section of Non-Fuel Products was organized in 1925. Prior to this time, various members of the staff had shared the work. Mr. J. E. Lamar, who joined the Survey in 1919, was placed in charge and has successfully developed the work to the present time. Special studies were made by Mr. Lamar on the molding sand resources of the State and on the geology and mineral resources of the St. Peter sandstone, as well as a reconnaissance survey of the mineral resources of Calhoun County. A study of the impurities of fireclays in fifteen different localities was made by Professor Parmelee and Mr. Lamar, and a manuscript report on the sand and gravel resources of northeastern Illinois was made by George E. Ekblaw and the Chief. A study of limestone for sewage filter beds, a field and laboratory study of the non-metallic mineral resources of southern Illinois, south of the coal field, a study of the limestone at Pontiac for cement manufacture, and a study of the cement resources of southwestern Illinois were made by Mr. Lamar, and last year studies were begun on the mineral resources along the new Illinois waterway, by T. B. Root and H. B. Willman under Mr. Lamar's direction, and of clays in Calhoun and southern Pike counties by Mr. Lamar and W. W. Rubey.

Most of these projects have been completed and the reports published. Those dealing with the non-metallic resources of southern Illinois, the mineral resources along the new Illinois Waterway, cement resources of southwestern Illinois, and the clays in northern Calhoun and southern Pike counties, are still in progress. The bulletin on the limestone resources of the State, which is based on studies made before 1923, by Frank Krey and Mr. Lamar, has been published. Many special services, too numerous to mention here, have been rendered.

New Study of the Origin of the Fluorspar Deposits

During the summer of 1926, the Survey was fortunate in securing the services of Professor E. S. Bastin, Chairman of the Department of Geology at the University of Chicago, in a study of the origin of the fluorspar deposits of Hardin County. The field work has been completed and the report will soon be in press.

Studies in Engineering Geology

The Section of Engineering Geology was organized in 1927, after the demands had become too great for the personal attention of the Chief, with Dr. George E. Ekblaw in charge. This section was the outcome of the increased number of requests from the State Highway Division for field conferences on the geological aspects of landslides, mud-flows, rock-falls, unequal settling of highway fills, road building across peat bogs, highway building materials, bridge foundations, etc. The prolonged wet season of 1926-27 induced much movement of earth materials in rough areas, where steep slopes and water-charged beds combined to make the earth materials unstable. At many places along Illinois River valley, material moved continuously onto the pavements; at some places the pavement itself moved, and in one instance the sub-grade and the pavement slid into an adjacent ravine. The correction of such conditions in many instances lies in draininge control according to the geologic relationships of the formations, or the area of water intake, or it lies in the replacing of talus material which had been cut away in highway construction, or in some other engineering procedure that is based on a knowledge of geological conditions.

The Survey has also been called upon for service in connection with the classification and estimates of materials to be excavated in making new highway locations and in connection with determining the foundation conditions for costly bridges, the geological conditions for surface water reservoir sites, the geological conditions likely to be encountered in the construction of subways, the likelihood of subsidence of factory sites over mined-out areas, the determination of the suitability of limestone for concrete aggregate, the question of using limestone sinks for sewage disposal purposes, a survey of the State's resources of road materials for the construction of the State's secondary highway system, and other kindred geological engineering studies.

Professor G. W. Pickels and Mr. F. B. Leonard made a complete revision of Bulletin 42 on Land Drainage, including the State drainage map, both of which have been published.

As the State continues to develop industrially it seems likely that this section of the Survey will be called upon increasingly for needed information.

Studies in Subsurface Data

The information which the industries, municipalities, state divisions, private citizens, and various organizations seek regarding subsurface conditions, requires a knowledge of all of the geological formations that lie upon the basement complex, aggregating in maximum thickness one and three-quarters miles. Their extent, character, relationship, structure, and useful resources must be investigated co-extensive with the boundaries of the State. The changes in these formations, whether in thickness, constitution, or structure, must be ascertained for each locality. It is therefore clear that the Survey's subsurface studies must be carried on competently and assiduously. To this end, when opportunity arose, a Section of Subsurface Studies was organized in 1926, with Mr. L. E. Workman giving his full time to the work. Previously, the work had had only the part-time attention of various individuals, who although competent, were assigned this work from time to time.

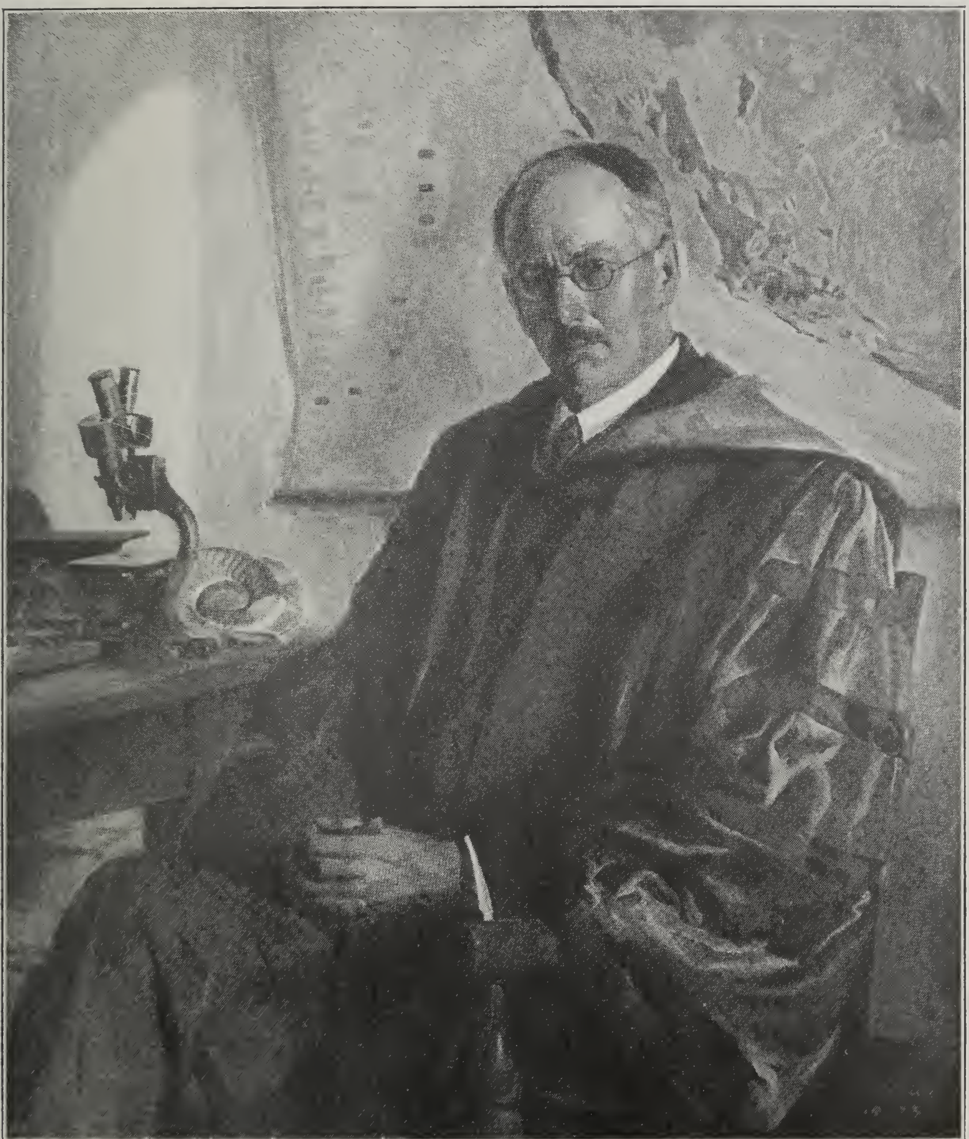
Since 1926, approximately 15,000 samples, representing about 150 wells, penetrating scores of thousands of feet of strata, have been studied. Geological information bearing on water supplies have been furnished to 116 villages and cities since the spring of 1927. All of this work has contributed to greater efficiency and economy in securing underground water supplies, in drilling, in proper casing of wells, in correcting or preventing pollution, in determining oil and gas structures, and in ascertaining the mineral resources of the formations.

On February 2 and 3, 1928, the Geological Survey participated with the Water Survey, the State Department of Public Health, and the departments of Theoretical and Applied Mechanics and of Farm Mechanics of the University of Illinois in calling a conference of the water-well drillers of the State for the purpose of carrying out an organization, whose aim would be to place the well drilling business on a scientific and efficient business basis and promote the preservation of subsurface data. These purposes are being attained. Many more subsurface data are reaching the Survey than ever before and drillers are receiving helpful scientific information for their guidance.

In 1929, a full-time water well and oil well scout was added to the staff to keep in constant touch with drilling operations and to secure and preserve information at the time that it is available.

Studies in Stratigraphy and Paleontology

The late Professor Stuart Weller of the University of Chicago continued his work on the stratigraphy and paleontology of the Mississippian system until his sudden death on August 5, 1927. It is with a deep sense of regret and loss that his death is here recorded. When the Survey was organized in 1905, Professor Weller was given the first appointment and he kept this connection on a part-time basis until his death. He began his work on the Mississippian formations because his chief interest lay in the problem of their differentiation. Although the problem at the beginning was mainly a scientific one, the results soon came to have important economic bearing on the exploration of the fluorspar deposits of Hardin County and on the deter-



STUART WELLER

mination of oil structures and the horizons of oil-bearing formations. The problem grew from a State problem to an inter-state problem with Missouri and Kentucky, and informal co-operation with the Surveys of those states was maintained. At the time of his death Professor Weller had nearly completed the gigantic task of detailed geologic mapping of the quadrangles of the Illinois Ozarks, south of the Coal Measures boundary. The faulted structure and the discontinuity of outcrops in this area required scientific work of a high order. Professor Weller left several unfinished manuscripts which deal with the stratigraphy, paleontology, and paleogeography of this area, and which were written from time to time during the progress of his work. These problems, however, were not completely solved and his death is keenly felt by the geological interests of the State and the geological profession of the country. Arrangements have been made for his son, Dr. J. Marvin Weller, to take up the work as soon as a sub-unit of his studies of the Pennsylvanian system is completed.

The preparation of a report on the stratigraphy and paleontology of the Silurian system of Illinois was undertaken by Professor T. E. Savage, of the University of Illinois, during the summer of 1924. The field work has been completed and some progress has been made in the study of the fossil collections.

The study of the paleontology and stratigraphy of the Pennsylvanian system was undertaken by Dr. J. Marvin Weller in the summer of 1926. During the field seasons of 1926, 1927, and 1928, he studied 651 outcrops and made collections from 375 localities. The study was extended into certain localities in the adjacent states of Indiana and Missouri where there are outcrops which throw light on the Illinois problem. The collections, which represent all of the important fossiliferous horizons, are the most extensive that have been made within this area and probably rank among the most valuable stratigraphic collections in this country. As the work progressed, Dr. Wanless came to be associated with Dr. Weller in the detailed study of the Pennsylvanian stratigraphy of western Illinois. Their results are notable and find expression in the papers which are to be presented at tomorrow's symposium on cyclical sedimentation during the Pennsylvanian period.

Dr. David White, principal geologist of the United States Geological Survey, has been devoting a portion of his time to a study of the paleobotany and stratigraphy of the Pottsville formation in Illinois, field work for which is nearly completed. The report will cover the Pottsville of the Eastern Interior Coal Basin. We are exceedingly fortunate in securing the services of this distinguished paleobotanist for this report which will be of a monographic order.

Dr. A. C. Noé, of the University of Chicago, has continued his paleobotanical studies of the Coal Measures which he began under the direction of

Mr. F. W. DeWolf. Large collections of plant fossils have been obtained, mostly from the Carbondale and McLeansboro formations although partly from the Pottsville, and some of them from sources heretofore regarded as non-fossiliferous. During the course of his studies, he has prepared an educational bulletin of wide interest on the Pennsylvanian flora of northern Illinois, that has been published. In 1922, Dr. Noé identified the first coal balls in the Coal Measures of North America, taken from coal No. 5 of the Harrisburg region by Dr. Cady in 1921. Polished cross-sections of these concretions reveal a wealth of scientific information concerning the morphology of the plants of Pennsylvanian times. Dr. Noé is now giving special attention to the preparation of a report on this subject.

Dr. C. O. Dunbar of Yale University, assisted by Mr. Lloyd G. Henbest of this Survey, has been making a paleontological study of fusulinas of the Coal Measures. These fossil forms have been found to be valuable indicators of the various limestone members of the Pennsylvanian system, and therefore will be helpful in correlation work. This study is well advanced.

The study of the Pleistocene deposits of southern Illinois has been given attention from year to year by Dr. J. Paul MacClintock, formerly of the University of Chicago and now of Princeton University, and the Pleistocene deposits of northern Illinois by the present Chief. The composite morainic belt of northeastern Illinois has been completely differentiated and the limit of the middle Wisconsin drift has been determined. Dr. MacClintock has studied the limit of the Illinoian drift sheet across southern Illinois, has established the existence of a sheet of pre-Illinoian drift underlying the Illinoian for most of southern Illinois, and has prepared two Reports of Investigations on the physiographic subdivisions of the area covered by the Illinoian drift sheet, and on recent discoveries of pre-Illinoian drift in southern Illinois. Dr. MacClintock and the Chief, with the co-operation of the State Soil Survey, have made a study of the profiles of weathering on the drift sheets of Illinois, with results that clarify problems of soil-making and soil-mapping and that illuminate interglacial history.

Studies in Areal Geology

Detailed geological mapping has been carried on in various parts of the State, covering a total area of nearly five thousand square miles. This department of work is now being supervised by specialists in the various divisions of the Survey. The results have been most helpful in determining the geology and mineral resources of the local areas, and in contributing materially to the solution of state-wide geologic problems. We are attaining, year by year, a clearer and clearer perspective of the geological frame-work of the State, and naturally this will promote important studies on mineral utilization. Our more detailed knowledge of the Coal Measures area of western Illinois will probably make possible a more comprehensive study of the Coal Measures of southern Illinois where outcrops are few and geologists must depend very largely on subsurface data.

A special piece of areal geology of note has been completed in southern Calhoun County, where the Cap au Grés fault and erosion has exposed a thick section of Paleozoic strata. This work has been competently executed by Mr. W. W. Rubey of the United States Geological Survey who was loaned to our Survey through the courtesy of the Federal organization at a time when all of the members of our staff were engaged in special projects. This splendid piece of co-operation is gratefully acknowledged. The co-operative piece of work between the Federal and State Surveys on the Geology and Mineral Resources of the Equality-Shawneetown Area, by Charles Butts, has been completed.

Educational Extension

The Section of Educational Extension was organized in June, 1929, just one year ago, to enable the Geological Survey to co-operate with the schools of the State, and to furnish teachers with information regarding the local and general geology of the State. Mr. Don L. Carroll was appointed to aid in this work. The following lines of endeavor will have special attention: (a) the preparation of a series of educational pamphlets which will cover the local and general geologic phenomena and geological history of the State; (b) the holding of field conferences by arrangement of the teachers for the purpose of acquainting them with their local geology; (c) distribution of collections of the rocks and minerals common to Illinois, together with labels and explanatory literature; (d) occasional talks and lectures upon invitation to high school or college science clubs, teachers, educational gatherings, etc. At the request of, and in consultation with, a number of the high school teachers of the State, the following schedule of field study conference trips have been planned for the current year:

May 10—Fox River Valley
May 17—Starved Rock Park.
Sept. 20—Mattoon-Effingham region.
Sept. 27—Modern coal mine in southern Illinois.
Oct. 4—Quincy region.
Oct. 11—Rock Island region.

Publications

From 1923 to present date, the publication of geologic information has continued along lines that are perhaps most readily shown by listing the various reports, several of which had been prepared under the direction of my predecessor.

Bulletin 43. Economic and Geologic Papers, 338 pages, 8 plates, 81 figures, 1923:
Geology and Mineral Resources of the LaHarpe and Good Hope Quadrangles: by T. E. Savage and M. L. Nebel.
Geology and Mineral Resources of the Morris Quadrangle: by H. E. Culver.
Geology and Mineral Resources of the Kings Quadrangle: by J. Harlen Bretz.
Geology of Northeastern Adams County: by Louis W. Currier.

Bulletin 44B. Oil and Gas Development in the Vicinity of Jacksonville: by D. M. Collingwood, 30 pages, 3 figures, 1923.

Bulletin 44C. Oil and Gas Development and Possibilities in Parts of Eastern Illinois: by L. A. Mylius, 64 pages, 7 plates, 3 figures, 1923.

Bulletin 45. Structural Reconnaissance of the Mississippi Valley Area from Old Monroe, Missouri, to Nauvoo, Illinois: by Frank Krey, 86 pages, 18 plates, 1924. In co-operation with Missouri Bureau of Geology and Mines.

Bulletin 46. Limestone Resources of Illinois: by Frank Krey and J. E. Lamar, 392 pages, 70 figures, 1925.

Bulletin 47. Geology and Mineral Resources of the Equality-Shawneetown Area; by Charles Butts, 76 pages, 3 plates, 6 figures, 1925. In co-operation with the U. S. Geological Survey.

Bulletin 48. Geology and Mineral Resources of the Carbondale Quadrangle: by J. E. Lamar, 172 pages, 5 plates, 28 figures, 1925.

Bulletin 49. Geology and Mineral Resources of the Dixon Quadrangle: by Russell Stafford Knappen, 141 pages, 5 plates, 20 figures, 1926.

Bulletin 50. Molding Sand Resources of Illinois: by M. S. Littlefield, 183 pages, 50 figures, 1925.

Bulletin 51. The Geology and Mineral Resources of the Joliet Quadrangle: by D. J. Fisher, 160 pages, 6 plates, 47 figures, 1925.

Bulletin 52. Pennsylvanian Flora of Northern Illinois: by A. C. Noé, 113 pages, 45 plates, 1925.

Bulletin 53. Geology and Economic Resources of the St. Peter Sandstone in Illinois: by J. E. Lamar, 175 pages, 3 plates, 43 figures, 1928.

Bulletin 54. Oil and Gas Development and Possibilities in East Central Illinois (Clark, Coles, Douglas, Edgar, and Parts of Adjoining Counties): by L. A. Mylius, 205 pages, 33 plates, 13 figures; 101 pages of tabulated well data, separately bound, 1927.

Bulletin 55. Geology and Mineral Resources of the Herscher Quadrangle: by L. F. Athy, 120 pages, 2 plates, 38 figures, 1928.

Bulletin 56. Illinois Coal: A Non-technical Account of Its Occurrence, Production, and Preparation, by A. Bement, 110 pages, 50 figures, 1929.

Bulletin 57. Geology and Mineral Resources of the Alexis Quadrangle: by Harold R. Wanless, 230 pages, 6 plates, 53 figures, 1929.

Bulletin 7. Physical Geography of the Evanston-Waukegan Region: by Wallace W. Atwood and James Walter Goldthwait, 102 pages, 14 plates, 52 figures, 1908. Reprinted 1925.

Bulletin 15. Geography of the Middle Illinois Valley: by Harlan H. Barrows, 128 pages, 16 plates, 47 figures, 1910. Reprinted 1925.

Bulletin 42. Engineering and Legal Aspects of Land Drainage in Illinois: by G. W. Pickels and F. B. Leonard, 334 pages, 1921. Revised, 1928.

Report of Investigations No. 1. Further Consideration of Prospects for Oil in the Decatur Area: by D. M. Collingwood, 44 pages, 1 plate, 1 figure, 1924.

Report of Investigations No. 2. Structure of Parts of Northeastern Williamson and Western Saline Counties: by Gilbert H. Cady, 20 pages, 3 plates, 2 figures, 1924. In co-operation with the U. S. Geological Survey.

Report of Investigations No. 3. Preliminary Report of an Investigation of the Molding Sand Resources of Illinois: by M. S. Littlefield, 37 pages, 1925.

Report of Investigations No. 4. Carbon Ratios and Petroleum in Illinois: by Gail F. Moulton, 18 pages, 5 figures, 1925.

Report of Investigations No. 5. Structure of Herrin (No. 6) Coal Seam near Duquoin: by D. J. Fisher, 34 pages, 2 plates, 15 figures, 1925.

Report of Investigations No. 6. Proper Testing for Oil Structures in Illinois and Some Areas Deserving Such Testing: by Gail F. Moulton, 22 pages, 9 figures, 1925.

Report of Investigations No. 7. Further Contributions to the Geology of the Allendale Oil Field, with a Revised Structure Map: by Gail F. Moulton, 27 pages, 4 plates, 12 figures, 1925.

Report of Investigations No. 8. Preliminary Report on the Economic Mineral Resources of Calhoun County: by J. E. Lamar, 21 pages, 3 figures, 1926.

Report of Investigations No. 9. The Glenwood Beds as a Horizon Marker at the Base of the Platteville Formation: by Arthur C. Bevan, 13 pages, 3 figures, 1926.

Report of Investigations No. 10. The Oölite of the Ste. Genevieve Formation: by J. E. Lamar, (reprinted from Transactions of Illinois State Academy of Science, Vol 18, 1925), 12 pages, 3 figures, 1926.

Report of Investigations No. 11. Pleistocene Studies: (1) A Notable Type Pleistocene Section:—The Farm Creek Exposure near Peoria, Illinois: by Morris M. Leighton; (2) Pre-Illinoian Till in Southern Illinois: by Paul MacClintock, (both reprinted from Journal of Geology, Vo. 34, No. 2, March-April, 1926). 15 pages, 5 figures, 1926.

Report of Investigations No. 12. Limestone for Sewage Filter Beds—Causes of Disintegration, Desirable Properties, and Methods of Testing: by J. E. Lamar, 21 pages, 5 figures, 1927.

Report of Investigations No. 13. Stratigraphy and Geologic Structure of Northern Illinois, with Special Reference to Underground Water Supplies: by F. T. Thwaites, 49 pages, 2 plates, 2 figures, 1927.

Report of Investigations No. 14. Present Status of Correlation of Illinois Coals: by Harold E. Culver, 13 pages, 1927.

Report of Investigations No. 15. Preliminary Report on the Fullers' Earth Deposits of Pulaski County: by J. E. Lamar, 31 pages, 8 figures, 1928.

Report of Investigations No. 16. The Oil and Gas Resources of the Ava Campbell Hill Area: by Towner B. Root, 27 pages, 3 plates, 4 figures, 1928.

Report of Investigations No. 17. The Limestone Resources of the Pontiac-Fairbury region: by J. E. Lamar, 27 pages, 7 figures, 1928.

Report of Investigations No. 18. The Gastropod Genus Yvania—Contribution to the Paleontology of Illinois: by J. Marvin Weller, 38 pages, 3 plates, 1929.

Report of Investigations No. 19. I—Physiographic Subdivisions of the Area Covered by the Illinoian Drift Sheet; II—Recent Discoveries of Pre-Illinoian Till in Southern Illinois: by Paul MacClintock, 57 pages, 27 figures, 1929.

Report of Investigations No. 20. Weathered Zones on the Drift Sheets of Illinois: by M. M. Leighton and Paul MacClintock, 53 pages, 6 figures, 1930.

Extension of Allendale Oil Field: by D. M. Collingwood, 8 pages, May 17, 1924.

Illinois Petroleum No. 1. Oil and Gas Possibilities near Sparta: by Gail F. Moulton; Petroleum Developments During 1925: by Gail F. Moulton, 8 pages, 1 figure, April 17, 1926.

Illinois Petroleum No. 2. Notes on a Core Bit for Cable Tools: by Gail F. Moulton; Prospecting for Hoing Sand Oil Pools: by Gail F. Moulton and J. Marvin Weller; Recent Petroleum Developments in Illinois: by Gail F. Moulton, 6 pages, May 29, 1926.

Illinois Petroleum No. 3. The Bearing of the Structural Relations Between the Pennsylvanian and Older Formations on Petroleum Prospecting in Western Illinois: by Gail F. Moulton; Oil Prospects in Central Pike County: by Alfred H. Bell; Current Oil Field Operations in Illinois: by Gail F. Moulton. 14 pages, 5 figures, July 24, 1926.

Illinois Petroleum No. 4. Areas for Further Prospecting near the Martinsville Pool, Clark County: by Gail F. Moulton; Oil Investigations in the Centralia Area—Preliminary Report: by Alfred H. Bell. 12 pages, 3 figures, August 28, 1926.

Illinois Petroleum No. 5. Oil Investigations in the Centralia Area—Preliminary Report (Concluded): by Alfred H. Bell; Oil-Field Water Investigations—Waterloo Field: by Gail F. Moulton; Oil Possibilities of the Ayers Anticline: by Alfred H. Bell; Current Oil Field Operations in Illinois: by H. C. Spoors, Jr. 24 pages, 5 figures, October 16, 1926.

Illinois Petroleum No. 6. The Sorento Dome (portions of Bond, Madison, and Montgomery Counties): by Alfred H. Bell. 11 pages, 3 figures, December 4, 1926.

Illinois Petroleum No. 7. Oil possibilities of the Payson Anticline, Adams County, Illinois: by Ben B. Cox; Petroleum in Illinois during 1926: by Gail F. Moulton. 12 pages, 3 figures, February 19, 1927.

Illinois Petroleum No. 8. Oil Possibilities of the Alexis Quadrangle, Mercer and Warren Counties, Illinois: by Harold R. Wanless; Summary of Oil Field Operations in Illinois during the first quarter of 1927: by C. R. Clark and A. H. Bell. 12 pages, 3 figures, April 16, 1927.

Illinois Petroleum No. 9. Oil Possibilities of the Galesburg Quadrangle, Knox and Warren Counties, Illinois: by R. S. Poor. 8 pages, 2 figures, June 18, 1927.

Illinois Petroleum No. 10. Structure of Centralia and Sandoval Oil Fields, Illinois: by A. H. Bell; New Producing Horizon in Wabash County: by Gail F. Moulton. 12 pages, 6 figures, July 23, 1927.

Illinois Petroleum No. 11. Recent Development in the vicinity of Jacksonville: by Alfred H. Bell. 12 pages, 2 figures, September 3, 1927.

Illinois Petroleum No. 12. Deeper Production in the Allendale Oil Field: by Gail F. Moulton. 19 pages, 2 figures, September 24, 1927.

Illinois Petroleum No. 13. The Media Anticline, Henderson County, Illinois: by A. H. Bell and L. E. Workman. 11 pages, 3 figures, January 28, 1928.

Illinois Petroleum No. 14. Structure and Oil Prospects of Eastern Clark County: by Gail F. Moulton and Jackson S. Young. 12 pages, 3 figures, March 17, 1928.

Illinois Petroleum No. 15. A study of the Core of the Yanaway Well No. 33 in the Siggins Pool: by J. E. Lamar; Corrosion in the Eastern Illinois Oil Fields; by J. E. Lamar and C. R. Clark. 22 pages, 1 figure, May 12, 1928.

Illinois Petroleum No. 16. Recent Development on the Ayers Anticline: by Alfred H. Bell; Recent Drilling Northwest of St. Francisville, Lawrence County, Illinois: by Alfred H. Bell. 18 pages, 5 figures, June 30, 1928.

Illinois Petroleum No. 17. The Dupo Oil Field: by Alfred H. Bell; Petroleum Production and Development in Illinois during 1928: by Gail F. Moulton. 20 pages, 3 figures, March 2, 1929.

Illinois Petroleum No. 18. The Darmstadt Anticline and Related Structures, St. Clair County: by Alfred H. Bell; Anticlinal Areas near Renault, Monroe County: by Gail F. Moulton. 16 pages, 3 figures, November 2, 1929.

Educational Series No. 1. The Story of the Geologic Making of Southern Illinois: by Stuart Weller. 42 pages, 12 figures, 1927.

Educational Series No. 2. The Rock River Country of Northern Illinois: by Deette Rolfe. 59 pages, 47 figures, 1929.

Illinois Mining Investigations Bulletin 28. Preliminary Report on Coal Stripping Possibilities in Illinois: by Harold E. Culver. 61 pages, 22 figures, 1925.

Illinois Mining Investigations Bulletin 29. Coal Resources of District III (Western Illinois): by Harold E. Culver. 128 pages, 2 plates, 14 figures, 1925.

Illinois Mining Investigations Bulletin 30, in co-operation with U. S. Bureau of Mines. Coal Losses in Illinois: by C. A. Allen. 36 pages, 7 figures, 1925.

Illinois Mining Investigations Bulletin 31. Coal Stripping Possibilities in Southern and Southwestern Illinois: by Gilbert H. Cady, 59 pages, 8 plates, 2 figures, 1928.

Illinois Mining Investigations Bulletin 32. Coal Stripping Possibilities in Saline and Gallatin Counties, near Equality: by Lloyd G. Henbest. 28 pages, 1 plate, 1929.

Base Map of Illinois, Fifth Edition (1925). In co-operation with U. S. Geological Survey.

Map and Directory of Illinois Mineral Industries, revised, 1927.

Map showing Status of Drainage in Illinois, revised, 1928, (See Bulletin 42).

TOPOGRAPHIC MAPPING

Increased appropriations for topographic mapping in co-operation with the United States Geological Survey became effective on July 1, 1923, the amount being increased from $35,000 to $50,000 per year, this sum being met, dollar for dollar, by the United States Geological Survey. From July 1, 1923 to June 30, 1930, the total mapped area of the State was increased from 22,300 square miles to 33,183 square miles, or from 39.4 per cent of the total area of the State to 58.6 per cent. In addition to this new mapping, a total of 1,823 square miles were re-surveyed, and primary traverse and primary leveling were completed for most of the remainder of the State.

Embraced in this re-survey are the revised maps of Chicago and vicinity on the enlarged scale of 1:24,000 with a five-foot contour interval. Similar maps have also been made covering the Springfield Sanitary District, East St. Louis and vicinity, and the Camp Grant Cantonment, the last with support from the Military and Naval Department of the State.

The completion of the mapping of the Chicago area was commemorated at a meeting of the Western Society of Engineers of Chicago, held on December 12, 1927, in which the Illinois Geological Survey and the United States Geological Survey co-operated.

The supervision of the field work was given devoted attention by Major W. H. Herron, Topographic Engineer in charge of the Central Division of the United States Geological Survey, from the early beginning of the co-

William Harrison Herron

operative work in 1906 until last October 9, when his sudden death deprived us of his most valuable services. Major H. H. Hodgeson was appointed by the Director of the United States Geological Survey to succeed Major Herron.

OFFICE PERSONNEL

Mention has been made in connection with the scientific activities of the Survey of the various personnel who have participated in responsible ways but it would be incomplete to close this record without giving the recognition that is richly due the clerical staff which has supported the scientific work on every hand. Miss Carrie H. Thory remained with the Survey until November 15, 1925, when, after having served efficiently for thirteen years as Chief Clerk, she was succeeded by Miss Emma J. Nyberg who had previously been Secretary to the Chief. Miss Zula Zeigler succeeded Miss Nyberg in the Secretary's position until she resigned January 31, 1927, at which time she was succeeded by Mrs. Margaret Moyer.

All of the present staff have participated whole-heartedly in carrying out the plans which have made possible this Quarter Centennial celebration.

THE SURVEY'S RELATIONSHIP TO INDUSTRIAL, SCIENTIFIC, COMMERCIAL, AND STATE ORGANIZATIONS

Constant effort has been made to keep the Survey and the various industrial, business, state, and scientific organizations in close contact. To this end, papers and addresses have been prepared and presented from time to time before the Western Society of Engineers, the Illinois Society of Engineers, the Chicago and St. Louis sections of the American Institute of Mining and Metallurgical Engineers, the Illinois State Academy of Science, the Associated Engineering Societies of St. Louis, the State Chamber of Commerce, the Conservation Council of Chicago, the Illinois Clay Manufacturers' Association, the American Waterworks Association, the Illinois Mining Institute, the Illinois Valley Manufacturers' Club, the University of Illinois, Northwestern University, Illinois Wesleyan University, and local organizations. The Survey has co-operated with the Illinois State Chamber of Commerce and the local chambers of commerce in many ways including the preparation of a chapter on "Mineral Resources" for the volume of the State Chamber of Commerce on "Illinois—Resources, Development, Possibilities."

Annually for three or four years, the faculties and graduate students of the departments of geology in the various universities and colleges of the State have been invited to participate in a field conference trip in areas where recent detailed geological work has been done.

Exhibits were prepared two years for the Illinois Products Exposition in Chicago, four years for the Illinois State Fair at Springfield, and one year for the International Petroleum Exposition at Tulsa, Oklahoma. On October 20-23, 1927, the Illinois Geological Survey was host to the Association of American State Geologists in a field excursion covering the geology and mineral resources of a part of northern Illinois from Peoria to Joliet. At this meeting, which was one of the largest that has ever been held by the Association, there were representatives from the United States Geological Survey, the National Research Council, American Museum of Natural History, University of Toronto, Russian Geological Survey, University of Chicago, University of Illinois, Northwestern University, University of Indiana, Illinois Wesleyan University, University of Nebraska, University of Cincinnati, and the University of Iowa. Complimentary bus service was furnished by the Public Service Company of Northern Illinois and the Illinois Power and Light Corporation.

Grateful acknowledgment is here made of the splendid co-operation and spirit of good will which the Geological Survey has enjoyed with the various departments of the State, including the Natural History Survey, the Water Survey, State Department of Mines and Minerals, State Department of Public Health, State Division of Highways, State Division of Waterways, State Division of Printing, and other departments.

The Survey has availed itself from year to year of the scientific resources of the three universities of this State and of universities elsewhere for special or continuing projects which could be carried on chiefly during the summers.

Part III

Research Needs of Illinois' Coal Industry

A symposium relating to recovery, preparation, marketing practice, utilization, and basic research

In cooperation with

Engineering Experiment Station, University of Illinois

Afternoon Session, April 30th

Professor A. C. Callen, *Presiding*

THE FUNCTION OF RESEARCH IN INDUSTRY

By Milo S. Ketchum[1]

INTRODUCTION

In the summer of 1928 when in London, I visited, among many other interesting places, the British Museum. The industrial exhibits in this museum indicate that the ancients were well versed in many of the industrial arts and that many of the ancient artisans were especially skillful. The ceramic industires were especially well represented. Due perhaps to the fact that the knowledge of these arts was in a few hands, the knowledge was lost with the passing of the individuals possessing the information.

The development of industrial nations has been largely due to a revival of the arts and crafts and the application of science and invention. In a great measure, the industrial activity in Great Britain was due to a knowledge of the methods of manufacturing steel and iron, Portland cement, and the other materials used in machines and structures.

In the beginning, most of the research was carried on by the individual industries, and the results of course were used by the industries for private gain. As the industries developed, however, it was found profitable to carry on the investigations through the cooperation of the members of a group of industries, either in public or private laboratories.

Research investigations may be of several kinds. Each manufacturer has production problems which are of special interest to him alone. These he can best solve in his own plant. There are other problems that are of peculiar importance to the entire industry. These include the development of equipment, standards of quality and workmanship, and they can best be conducted on a cooperative basis.

DEVELOPMENT OF ENGINEERING RESEARCH

In the United States, engineering research investigations are now being carried on in the laboratories of many of the industries, in private commercial laboratories, by the federal government in such laboratories as the Bureau of Standards, in state laboratories, in the laboratories of state universities, and in privately endowed colleges and universities.

[1] Dean of the College of Engineering and Director of the Engineering Experiment Station, University of Illinois.

The first engineering colleges in the United States were virtually liberal arts colleges with a few subjects covering the art and science of engineering. As a result of the Morrill Act, land grant colleges and universities were established in practically every state in the Union, and in these institutions the engineering curriculum was given a place comparable with that of liberal arts and agriculture. With the engineering college as a separate entity, engineering research has developed in a wonderful way in Land Grant and state institutions.

The first regularly organized engineering experiment station was established at the University of Illinois on December 8, 1903. In 1904 an engineering experiment station was established at Iowa State College. The number of engineering experiment stations has increased very rapidly since that time and there are at present thirty-six engineering experiment stations in land grant institutions. In addition, there are a number of engineering experiment stations in state universities which are not land grant institutions, and a considerable number of engineering experiment stations are in endowed colleges and universities.

WORK OF AN ENGINEERING EXPERIMENT STATION

Scope of Work

An engineering experiment station in a state university must carry on its investigations for the benefit of industry and ultimately for the benefit of the public. This limitation naturally restricts many of the investigations that can be undertaken by these experiment stations. At the University of Illinois in all cooperative investigations, the University reserves the right to carry on the investigations in its own way with assistants employed by the University. It also reserves the right of publication, and all inventions and discoveries belong to the University.

In carrying on engineering research, it is oftentimes necessary to develop new processes and new methods. If the scientific knowledge at hand is inadequate, it may be necessary to undertake investigations in pure science in order that the problem can be solved.

Engineering research differs from so-called "pure" research in that the principal aim of the former is to solve some definite problem. Ordinarily, engineering research is conducted on a somewhat larger scale than research in pure science. If the methods or knowledge available in pure science is not sufficient for our purpose in engineering research, new methods and new data must be obtained. In many cases, this makes it necessary to carry on very extensive investigations in the field of pure science. For example, in the investigation of fissures in steel rails now in progress at the University of Illinois, it has been necessary to develop a new method for the mathematical analysis of the stresses in the head of the rail.

When structures and machines were of simple character, a knowledge of the common physical properties of steel was adequate for design and construction, but with the tremendous increases in requirements in modern industry, in pressures, speeds, temperatures, and similar essentials, this elementary knowledge of properties of materials became quite inadequate.

For several years Professor H. F. Moore at the University of Illinois has carried on investigations in the fatigue phenomena of metals, which have been financed by the Engineering Foundation, the General Electric Company, and several other companies. The results of Professor Moore's investigation have given the Engineering Experiment Station and Professor Moore world-wide recognition. One of the faculty of the University of Liverpool spent more than a year in Professor Moore's laboratory, and last year a professor from the University of Budapest spent several months working under the direction of Professor Moore.

Cooperation with Industries

Although it is necessary that the permanent staff of an engineering experiment station be supported by the state or by the institution, it is not possible to carry on all the needed lines of investigation in the Engineering Experiment Station without the cooperation of the industries. At the present time, the State of Illinois is furnishing nearly $100,000 for the support of the Engineering Experiment Station, but in addition to this, more than $150,000 a year is being furnished by various industries to carry on 36 special cooperative investigations which are of especial value to them. These investigations are carried on with a staff of men working on full time, with many others working on part time.

Training of Research Workers

The research graduate assistants at the University of Illinois are part-time workers, whose services are invaluable in the work of the Station and whose training on these investigations under famed investigators is invaluable to themselves. They are appointed for two years and give one-half their time to research and one-half their time to graduate study. More than one hundred of these research graduate assistants have completed their work and have received either the degree of Master of Science or of Doctor of Philosophy. These men have been uniformly successful and are now occupying positions of responsibility with the industries, in research, and with educational institutions. Although the results of the various researches carried on in the Engineering Experiment Station of the University of Illinois have been of great value to the industries, there is little question but that the men trained in the Station have been worth a great deal more than the data obtained in the investigations.

Publication of Results of Research

The results of the research investigations in the Engineering Experiment Station of the University of Illinois are given in more than two hundred bulletins and circulars published by the University. These bulletins cover investigations of materials, including cement, steel, and ceramic materials, and many others on problems pertaining to the mining industry.

Two of the early bulletins published in cooperation with the State Geological Survey appeared in the very early days of the Engineering Experiment Station, one "Investigation of the Fire Clay of the State," by R. C. Purdy and F. W. DeWolf, was published in 1906, and the second, "Paving Brick Clays of Illinois," by A. N. Talbot, I. O. Baker, C. W. Rolfe, and R. C. Purdy, was published in 1908.

As early as 1911, the Engineering Experiment Station cooperated with the federal Bureau of Mines and the Illinois State Geological Survey Division in carrying on research in the coal resources of the State. In 1926 the Bureau of Mines withdrew from this cooperative arrangement, but the Geological Survey and the Engineering Experiment Station are still cooperating on these very important problems.

As a result of this cooperation, a great many valuable bulletins have been published on the coal resources of Illinois. Nine bulletins and nine technical papers have been issued by the U. S. Bureau of Mines. Twenty-three bulletins have been published by the Geological Survey Division, and twenty-one by the Engineering Experiment Station. Several of the more recent bulletins published by the Engineering Experiment Station on the cooperative mines work are: No. 158 "The Measurement of Air Quantities and Energy Losses in Mine Entries," by A. C. Callen and C. M. Smith, No. 170 "The Measurement of Air Quantities and Energy Losses in Mine Entries," Part II, by A. C. Callen and C. M. Smith, No. 184 "The Measurement of Air Quantities and Energy Losses in Mine Entries," Part III, by A. C. Callen and C. M. Smith, No. 196 "An Investigation of the Friability of Different Coals," by C. M. Smith, No. 199 "The Measurement of Air Quantities and Energy Losses in Mine Entries," Part IV, by C. M. Smith.

The publications of the Engineering Experiment Station include many other bulletins besides the coal mining bulletins which are doubtless of interest to the mineral industries. For instance: "The Thermal Conductivity of Fire Clay at High Temperatures," "Dissolved Gases in Glass," "The Viscosities and Surface Tensions of the Soda-Lime-Silica Glasses at High

Temperatures," "An Investigation of the Translucency of Porcelains," "The Measurement of the Permeability of Ceramic Bodies," "A Study of Hard Finish Gypsum Plasters," "The Thermal Expansion of Fireclay Bricks," "A Laboratory Furnace for Testing Resistance of Firebrick to Slag Erosion."

In conclusion, may I express our very great appreciation of the sympathetic support and able cooperation of the State Geological Survey Division which we have always enjoyed in our joint investigations of the coal mining problems in Illinois. We trust that the work has been mutually profitable and that it will continue indefinitely under the same pleasant arrangement, to the great benefit of both geology and engineering.

A MINING ENGINEER'S VIEW OF THE FUTURE OF ILLINOIS COAL INDUSTRY FROM THE STANDPOINT OF RECOVERY

By John A. Garcia[1]

PURPOSE AND SCOPE OF THIS ARTICLE

It is the purpose of this discussion to submit the opinion of a Mining Engineer as to how the Geologist may best serve the coal mining industry in planning his schedule of research or investigation for the next several decades. The idea was prompted by the realization that the rapid depletion of those seams of coal in Illinois whose characteristics, from the standpoint of both combustion and mining, lead to immediate exploitation, will soon bring up the problem of substitution when these better coals are exhausted.

COAL RESOURCES

Because of our wasteful mining system it is estimated that the 120 billion tons, more or less, of coal under the prairies of Illinois will last only about 375 years, but our best seams have a much shorter life if present mining and combustion methods are continued.

From Bulletin 15 of the Cooperative Agreement[2] we find the available coal from the No. 6 seam in District No. VI to be about five billion tons at a 56 per cent extraction, and Bulletin No. 19[3] cites in District No. V a total of about three billion tons at 60 per cent extraction for both No. 5 and No. 6 coals. Those two districts embrace Franklin, Williamson, Jefferson, Saline, and Gallatin Counties, an area from which comes the coal generally considered to be of the highest quality in the State. The combined available coal resources of the two districts is approximately eight billion tons.

The low sulphur area in Franklin County was opened up in 1904 and the production mounted rapidly through the years until today it is one of the leading, if not the leading county in the output of Illinois coal. The decline in production from longwall mines coincided with the increase from the thick seam district, as might be expected when the difference in mining cost, as well as quality, is considered, but the shift in production was so rapid and radical that the whole economic structure of the industry was changed.

The following table illustrates this history-making epoch in Illinois mining and indicates clearly the intensive exploitation of our best coals:

---

[1] Allen and Garcia Company, Chicago.

[2] Cady, G. H., Coal Resources of District VI: Illinois State Geol. Survey, Coop. Mining Series Bull. 15, 1916.

[3] Cady, G. H., Coal Resources of District V: Illinois State Geol. Survey, Coop. Mining Series Bull. 19, 1919.

TABLE 1.—*Coal production in La Salle and Franklin counties, showing the southward shift in production*

		La Salle County Tons Produced	Franklin County Tons Produced
1904		1,773,000	None
1910		1,302,000	2,071,000
1915		1,274,000	7,324,000
1920		865,000	11,300,000
1925		641,000	13,082,000
1929	(approximately)	334,000	14,720,000

EXTRACTION

The mining conditions in La Salle and Franklin Counties are, of course, totally different. In La Salle County coal No. 2 is about 3½ feet thick and is worked by the longwall method of mining, whereas in Franklin County the No. 6 seam averages 9 feet in thickness and is worked by the room-and-pillar or panel system. The percentage of extraction for La Salle may be taken at 95, but for Franklin County No. 6 seam it varies from 40 to 50.

The following figures on coal losses and extraction are summarized from the tables presented by C. A. Allen[4] and were compiled after a comprehensive and systematic survey by the Commission:

TABLE 2.—*Summary of coal losses in Illinois*

Reason for Loss	Peoria and Fulton Coal No. 5	Central & Belleville No. 6	Springfield Nos. 5 and 6	Southern Ill. No. 6	Saline County No. 5	Danville Nos. 6 and 7	Longwall No. 2
	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Left as roof and bottom coal	None	0.7	Fraction of 1	7	None	None	Fraction of 1
Room, entry and panel pillars	35	43.0	44	41	38	32	None
Oil and Gas-well pillars	None	None	None	None	None	....	None
Bldg. R. R. and boundary pillars	....	0.8	....	1	......	....	Fraction of 1
Mining and preparation loss	3	2.7	4	3	3	4	5
Rolls, thin or dirty coal, faults, streams, etc.	15	0.3	3	1	5	7	None
TOTAL LOSS	53	47.5	51	53	46	43	5
Avoidable loss	28	26.0	26	36	31	23	0
Possible to extract	75	77 to 80	75	83	85	80	....
Average present extraction	47	52.5	49	47	54	57	95

[4] Allen, A. C., Coal losses in Illinois: Illinois State Geol. Survey, Coop. Mining Series Bull. 30, 1925.

Illinois—Exclusive of Longwall Field

Average Extraction	50.3 per cent
Average Loss	49.7 per cent
	100.0 per cent
Avoidable Loss	32 per cent
Possible to Extract	82 per cent

If this 32 per cent were saved, the depletion charge on coal acreage would decrease about 25 per cent—enough to pay for surface rights in most sections of Illinois.

Although this table indicates only a small variation of from 47 to 57 per cent extraction in the different districts employing the room-and-pillar method, the fact is that a much wider range exists between individual mines and even districts. The calculations, or estimates, made by the authors of the many publications examined by the writer were probably as accurate as possible considering the many varying factors involved in the problem and the meager data available, but the figures were all compiled from operating or live mines and one very large source of lost coal was not considered; that is, the abandoned acreage in mines that fail, for one reason or another, to reach what might be termed the economic limit of assigned acreage. There are many such abandoned mines in Illinois and Indiana and most of them leave strips or tracts of coal acreage beyond the faces that cannot be worked from other mines, as shown in Figure 6.

Probably the best way to secure reliable data on extraction percentages is to make an accurate survey of a mine when abandoned, planimeter the meandering line of the working face for acreage depleted and take the hoisting record for tons produced. From these basic data can then be calculated the tons per acre extracted and the loss of boundary coal. By systematic measurements in all parts of the mine a fair average thickness of the seam may be arrived at which would permit of calculating within reasonable limits the actual percentage of extraction over the whole period of the mine's life, which is the real base to use when figuring extraction. It may be stated here that in the writer's experience very few room-and-pillar mines in Illinois, of any size, have averaged throughout the life (or over a substantial period of years) an extraction of 56 per cent which is the "rule of thumb" figure used in this section of America and reached by the simple rule of 1,000 tons per foot per acre. Close examination and inspection of many properties for the purpose of making engineer's reports for financing, places the percentage at an average of less than 50 and in some of the most ambitious operations in Illinois, near 40. (See Fig. 7.)

REASONS FOR LOW EXTRACTION PERCENTAGES

There are some excuses, but many good reasons why the coal operator of Illinois loses more than half his acreage in winning the coal. Mismanagement, carelessness, and ignorance account for only a small part of the total loss, for the Illinois mining man ranks near, or at the top, of the list as to competency and application. The economic and labor conditions, how-

FIG. 6. Plat showing abandoned mines and lost boundary coal.

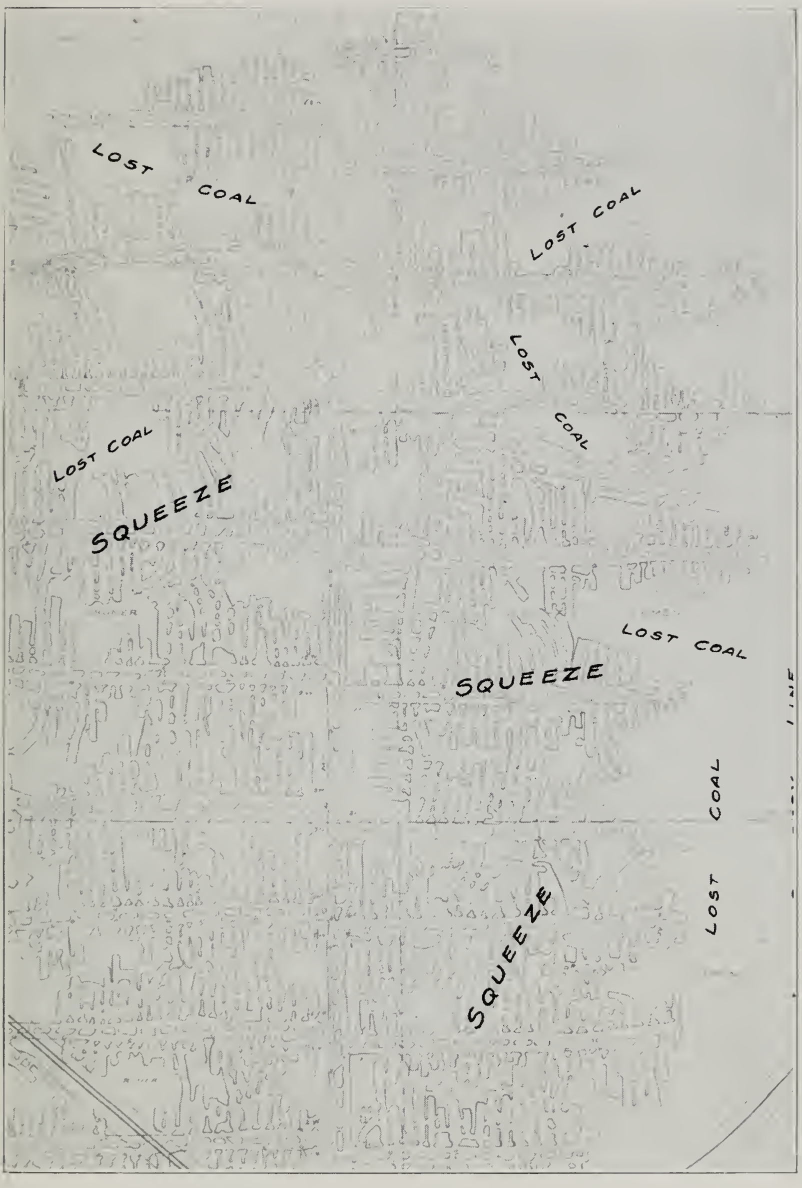


FIG. 7. Workings of an abandoned mine illustrating lost coal areas due to non-systematic layout and squeezes.

ever, together with the necessity of producing coal at an extremely low cost, forces him to forget, or at least defer, the day when he may establish systematic pillar-drawing or "robbing."

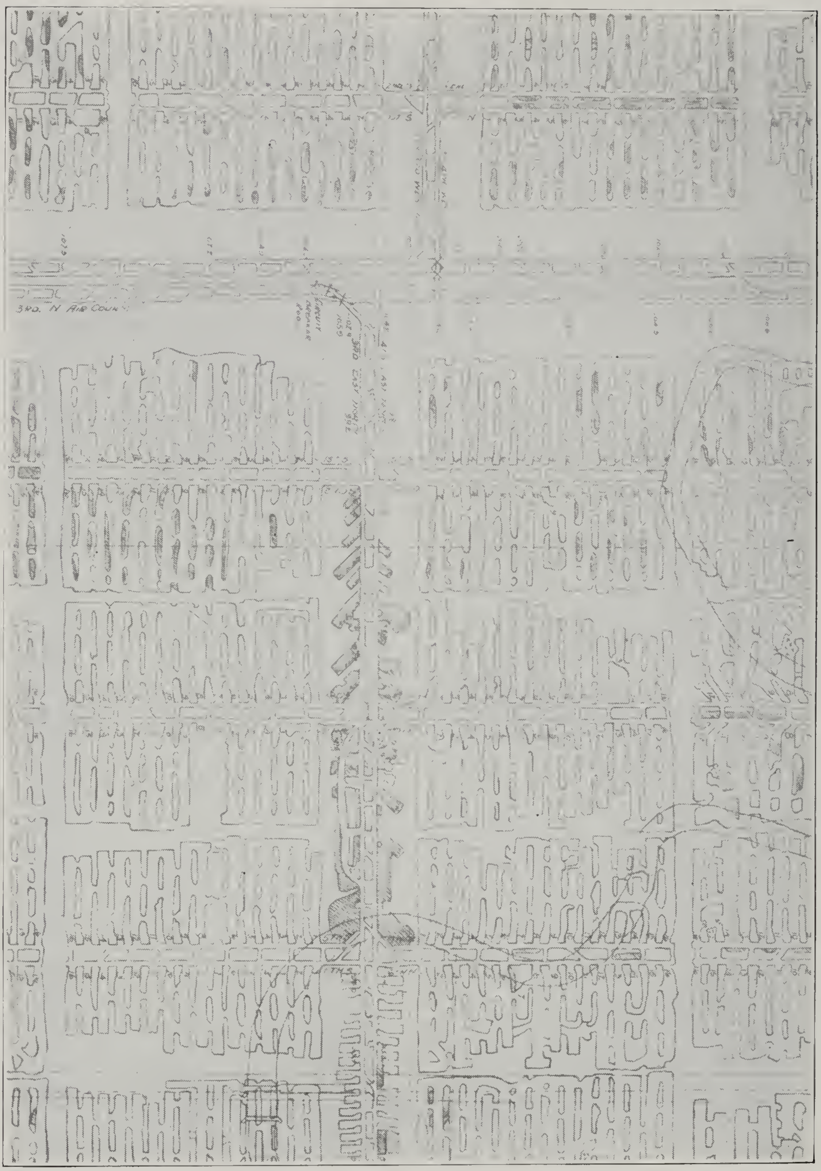


FIG. 8. Typical panel system at a modern Illinois mine illustrating the ratio of wide to narrow places and also so-called "pillar-drawing."

To keep this paper within reasonable limits of its scope, only a few of the major reasons for the Illinois mining man's alleged "disgraceful" waste of our coal resources are cited.

First, the contract with labor which imposes a premium known as "yardage price" on all narrow or development work. It is quite impossible to design a mining system without liberal use of "narrow" places, and the application of yardage costs—together with other contract requirements—forces the maximum percentage of wide places in a given area if competitive costs are to be obtained. (Fig. 8.)

Second, the excessive surface cost per acre allowed by the courts in damage suits for subsidence or the alternate burden of "carrying charges" and taxes on surface land should the operator purchase his acreage in fee.

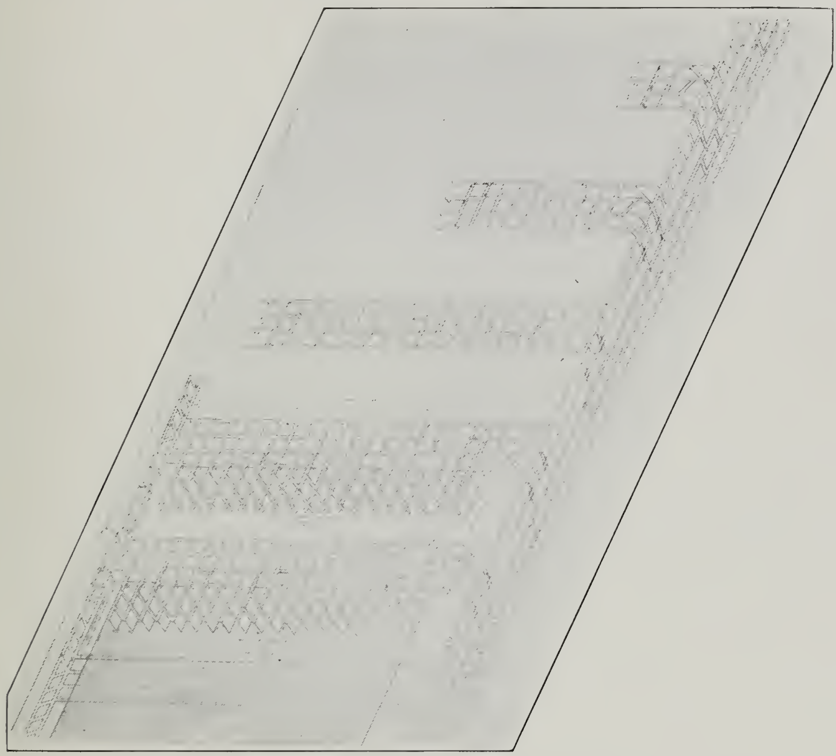


Fig. 9. New mine in Pennsylvania workings designed for 95 per cent recovery and complete mechanization.

The average cost of Illinois surface land is higher than that of most other coal producing states.

Third, the increased amount of screenings or small size coal made by increasing the percentage of narrow work and by pillar drawing.

Fourth, the intermittent running time at Illinois mines, for an important element in the plan of systematic pillar-drawing is continuous operation. Any extended period of mine idleness would be nearly fatal to such methods.

WHAT THE FUTURE SHOULD BRING

The geologist can be of assistance to the mining industry in the solution of these four problems affecting extraction by compiling, in one volume, old and new data bearing on these questions and possibly by using proper influence to correct the evils in court procedure in subsidence cases. The mining engineer's answer to the whole problem is complete mechanization and plants for cleaning the output.

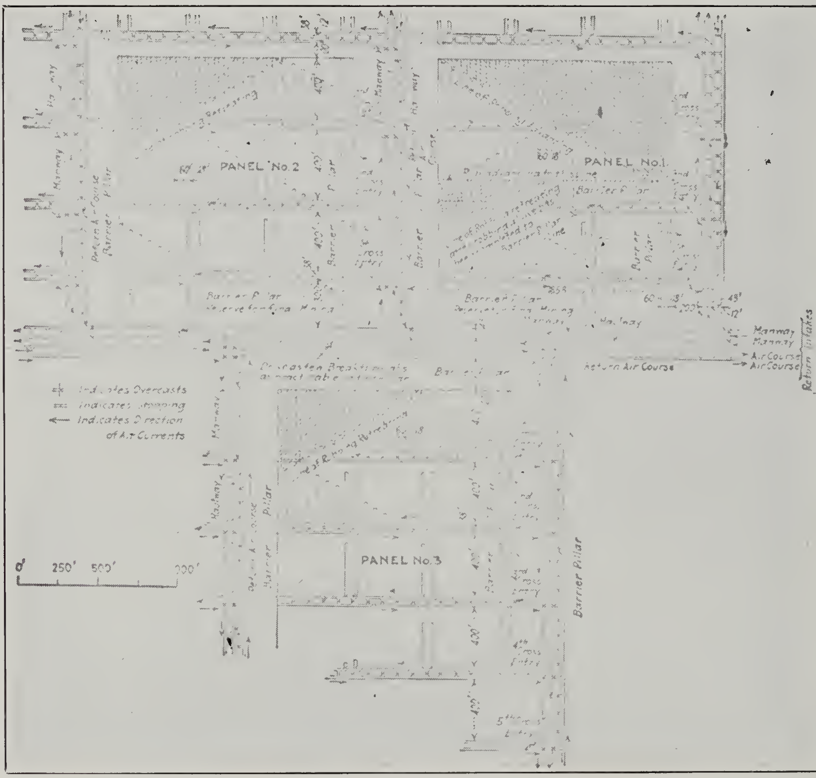


Fig. 10. A West Virginia mining plan showing panel system designed for 95 per cent recovery.

The establishment of rib-robbing lines and systematic pillar-pulling is a fairly simple problem for practically all Illinois coal mines and there would be very little experimental methods involved, excepting as to minor details, in adapting one of the many established systems to the special conditions of the individual operation. Complete mechanization for drilling, cutting, loading, hauling, hoisting, and preparation means rapid advancement of development work, with resultant concentrated mining, and though it also means a dirtier primary product, the mechanical cleaner can correct that. (Figs. 9, 10, and 11.)

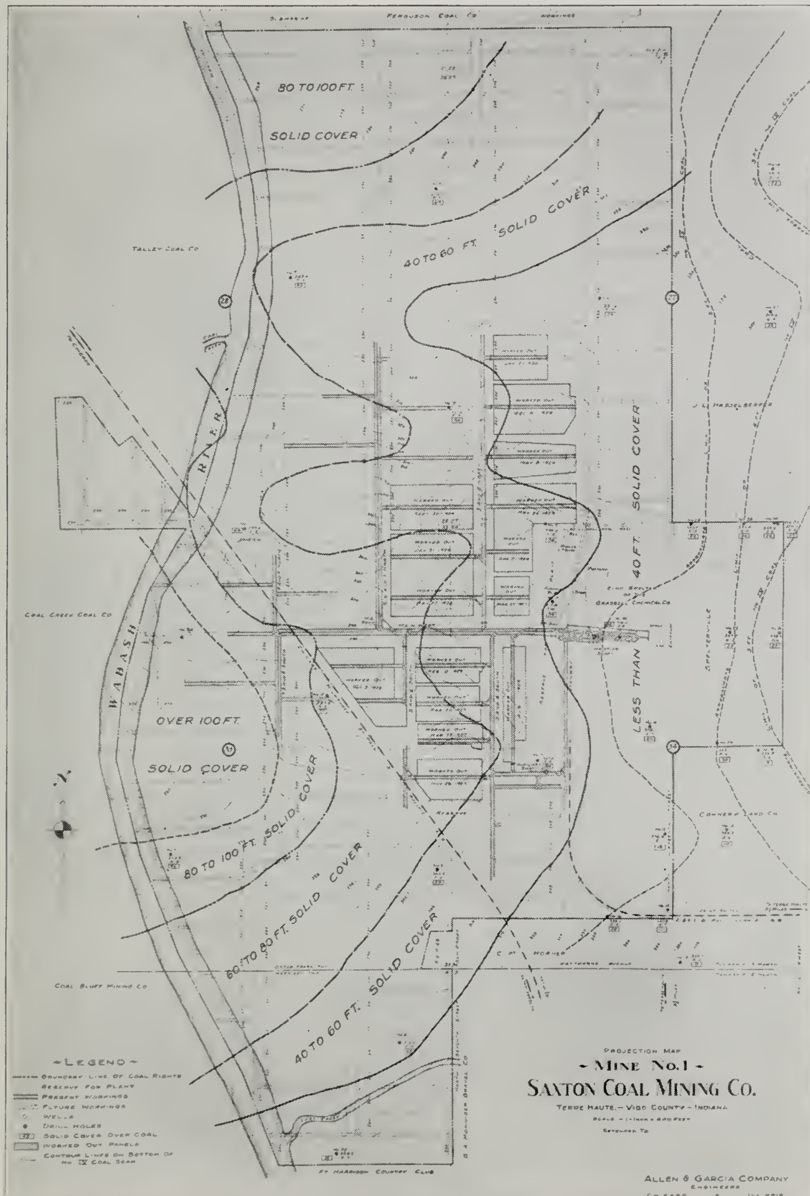


FIG. 11. Panel system of an Indiana mine designed for 50 per cent recovery on account of water-bearing overburden.

The geologist is directly concerned, for many reasons, in the successful introduction of loading machinery in Illinois mines and in the development of equipment for cleaning coal, particularly because seams not now worked, due to non-competitive conditions with hand-loading, may be very profitably worked with complete mechanization. It is readily conceivable, therefore, that the thinner coal seams of Illinois, especially those with low freight rates to the general markets, may come back into the picture, and it behooves the geologist to "dig and discover" the characteristics of those coal beds which are adapted to ready application of mechanical operations, characteristics such as levelness, type of roof, presence of faults, amount of water, the surface topography as affected by subsidence, etc.

The screenings problem must be solved by the chemist and combustion engineer and they have gone a long way in the last ten or fifteen years. Until 1899, the percentage of screenings at Illinois mines averaged 25 per cent of the output, but in that year the mine-run basis of payment was adopted and the percentage of small coal produced rose abruptly to 55 per cent. From 50 to 55 per cent of two-inch screenings has been normal at most mines ever since. This situation was met by the mechanical engineer in the design of special equipment for burning screenings, such as stokers, powdered coal apparatus, forced draft, etc., and in the last few years, the stoker for domestic use. It is true that in the last 25 years the amount of coal used to generate a kilowatt-hour has been reduced from five pounds to almost one, thereby further limiting the market for screenings, but this has been offset by the enormous increase in the production of electric energy, whose volume curve goes up sharply each year and will surely continue to rise until the demand for screenings will automatically eliminate the differential in price between lump and small coal.

When the chemist or metallurgist has done his part and low-temperature distillation of Illinois coals has become commercially feasible, the mining engineer and the geologist will have opened to them new fields to conquer, for if we may be permitted to design and build a coal mine to produce screenings only, we will have reached our ideal in operation and the geologist will be confronted with the task of developing new data on old coal fields to be studied in the light of such radical changes in mine requirements.

EXTRACTION AND STRIP-MINING

The strip-mining branch of the industry is now an important factor to be reckoned with as may be noted from the following production table for Illinois alone:

Table 3.—*Percentage of coal produced by strip-mining*

Year		Output	Percentage of State Total
1914		324,487	Negligible
1917		542,801	.6
1922		720,060	1.2
1924		2,295,860	3.4
1926		3,461,098	5.0
1928		4,345,000	8.0
1929	(Approximately)	5,104,653	9.0

In the United States, approximately 20,000,000 tons of coal is now won in a year by the stripping method—about 4 per cent of the total bituminous output—and undoubtedly this percentage will increase for some years. The extraction in the Illinois pits may be fairly averaged at 85 per cent, although some operators claim 95 or even 100 per cent, but knowledge of many pits has convinced the writer that 85 per cent is the more conservative figure, especially for very thin seams where an inch or so of bottom coal may be 5 per cent or more of the whole, thus radically affecting the ratio of extraction. The ribs along the spoil bank, faulty areas, tracts inaccessible on account of shape, severe grades, etc., all combine to make a sizeable total and must be considered in calculating extraction. (Fig. 12.)

Splendid service has been rendered the strip coal operator by the geologist and the industry has profited greatly by the publication of such Bulletins as Nos. 28, 31 and 32, of the Cooperative Mining Series. The recovery of many millions of tons of Illinois coal was hastened and prospecting costs were much reduced as a result of these studies.

Although a bulletin on "Coal Stripping Possibilities in Southern and Southwestern Illinois,"[5] was issued in 1927, it appears as though a supplementary report will be needed in a few years because of the great strides made each year by the manufacturers of equipment for this class of work, making possible the profitable exploitation of thin seams having a high ratio of overburden but located close to markets. In the northern Illinois field, the thin No. 2 seam is now stripped where ratios of overburden to coal are as high as thirteen to one, and by supplementing the digging shovel with drag lines, several of these pits will soon be operated where the ratio is twenty-to-one, but this is exceptional and possible only because the overburden requires no shooting and the market is practically right at the pit.

Up to sixty feet of cover is removed today, where forty was the limit ten years ago, and large tracts with a stratum of hard rock in the overburden are readily stripped by the present huge shovels and with the generous use of explosives, whereas, in 1920, or even 1925, such areas were not considered

[5] Cady, G. H., Coal Stripping Possibilities in Southern and Southwestern Illinois: Illinois State Geol. Survey, Coop. Mining Series Bull. 31, 1927.

desirable. Drainage system, pumping equipment, purchased power, pit car design, liquid oxygen, and numerous other items of improvement have made it necessary for us to revise our preconceived ideas of possible strip areas, and our data as listed in publications available at the present time may be obsolete in a few years, insofar as potential strip acreage is concerned.

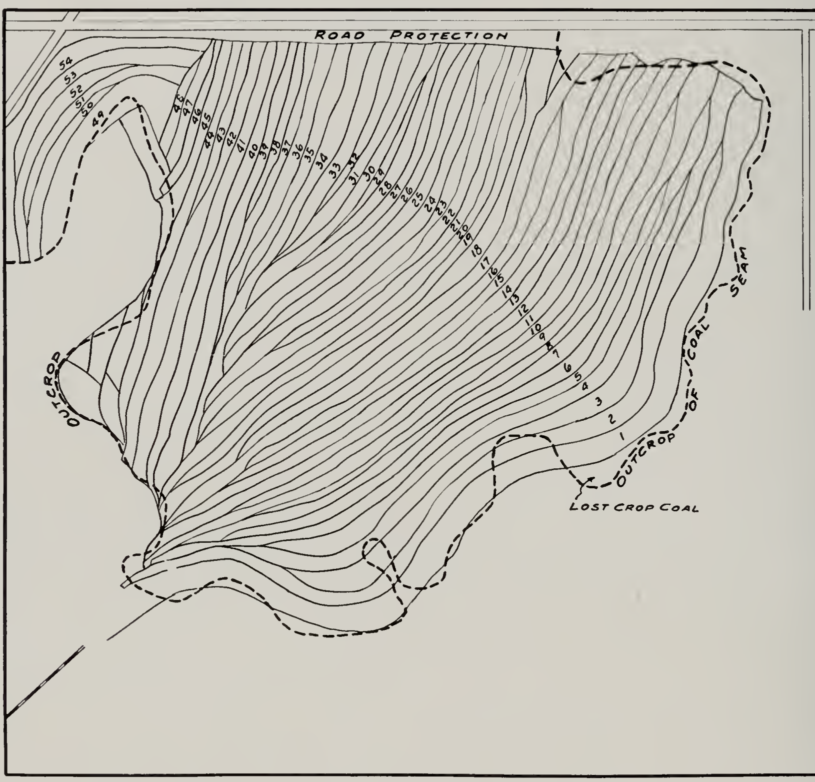


FIG. 12. Map of modern strip pit showing high percentage of recovery. Each cut is indicated as actually made.

STORAGE OF COAL

The State Survey has done some very fine work in connection with coal storage and much valuable data have been published. This question is related to extraction, in that when a mine is mechanized, pillar-drawing and rib-robbing lines will be much more practicable and profitable, but this, in turn, demands fairly continuous operation. Now, should the modernization schedule follow its proper sequence and production of lump coal become a minor instead of a controlling factor as at present, the mechanical features in the design and layout for coal storage will be greatly simplified. Add to this the mechanical cleaning of small-sized coal and elimination of depreciation in values because of degradation, then storage—both ground and under water—becomes more a question of financing costs than an engineering problem.

In Europe efficient utilization and storage of coal has always been given more consideration than in America, chiefly perhaps because of the comparative investment and production costs and the limited natural resources, but we must put an end to our waste of better grade coals or we shall face the same situation. The writer's work in Russia has to do with the construction and development of coal mines and in each instance the plans include mechanization, cleaning plants, 75 to 90 per cent extraction of each workable seam, and storage of output at the mine to permit steady hoisting in event of car shortage whether due to slow market for certain sizes or to other causes that interrupt operations. In some instances, backfilling by pneumatic or a water flushing system must be provided to protect against subsidence or to aid in obtaining high extraction percentages.

SUMMARY

In view of the foregoing, it is suggested that the geologist henceforth collect and present his data with special consideration for the effect of mechanization, cleaning plants, and new methods of utilization on the present mining methods of Illinois. He should continue to furnish information that aids in prospecting and to publish reports, maps, folios, etc., for these are practically indispensable for the intelligent projection of workings or planning of new operations. Mining systems used in other states showing pillar-drawing methods might well be studied to determine those most suitable to Illinois conditions. He should assume that when this era of factory process shall have arrived, concentrated mining with resultant high percentage of extraction will be part of the program, and from his intimate knowledge of the characteristics of each Illinois coal seam he should be able to make a table showing the possible available tonnage from Illinois coal measures under the proposed system, and to demonstrate by comparison with the figures compiled in conformity with present practice, the great increase in fuel resources and life of existing mines.

It does not mean much to the average layman for the geologist to tell him that we have a hundred billion tons or so of available coal in Illinois and that it will last three or four hundred years, but it does mean something to say that with more modern methods of mining and processing of output, we could increase our fuel resources fifty per cent, decrease the cost to the ultimate consumer, and give him a lower ash coal. Also, it would mean a great deal to the coal operator if the geologist would show on his maps those areas where the seams, because of physical conditions and location relative to market, indicate successful exploitation with complete mechanization and the consequent decrease in amortization charges due to higher extraction and longer life.

CONCLUSION

It appears certain that we of the coal mining industry of Illinois are at the threshold of the door that opens to new and greater opportunities. The passing generation of coal men has had no easy path; there have been cycles through the years when great momentary prosperity brought hysteria and then—long periods of depression and distress. With the geologist to point the way, the engineer to direct the methods of extraction, and with a sound economic structure, it is possible to almost double our precious heritage of coal and in that thought lies the inspiration for further cooperation and renewed effort.

COAL PREPARATION AND RESEARCH FOR FUTURE NEEDS

By E. A. Holbrook[1]

COAL PREPARATION RESEARCH

Eighteen years ago the writer, while engaged in teaching and research work in Nova Scotia, was visited by the late Dr. H. H. Stoek, who stated that research in coal preparation was one of the visions he had for his newly established department of Mining Engineering at the University of Illinois. "Certainly," he said, "since research has so advanced the preparation of ores and other minerals, there must be a field for similar work in coal." The next fall the writer came to the University of Illinois and during the following five years was connected with the University, devoting part time to coal preparation investigations under Dr. Stoek. Later this work was conducted by Professor Ray Arms, and through cooperation with the U. S. Bureau of Mines, by Mr. Thomas Fraser and Dr. H. F. Yancey. Since then the work has been carried on under the direction of Professor A. C. Callen.

Out of the research work in coal preparation at Illinois has come technical knowledge that has made possible new methods and machinery in coal preparation; for example, the application of the so-called Concentrating Table to the cleaning of fine coal, and a knowledge of the relative importance of sizing in coal cleaning operations. Several advances in the art of screening resulted from work in the laboratory. During the war, methods of recovering pyrite from various Illinois coals were developed to a point, where, had the need for sulphur continued, a considerable number of plants would have been in operation. Later a successful coal cleaning table using air as a separating medium was perfected and the principle of the so-called air-sand separation process was worked out. Advances were made in our knowledge of the so-called float-and-sink test in coal preparation, and the now familiar washability curves were perfected from which the probable success or failure of a coal cleaning operation can be forecast. Again, progress in developing the laws of breakage or degradation of coals made in the laboratory here has promising applications.

The value of the coal preparation laboratory at the University of Illinois has been not alone in its technical productions, but rather, its greatest values have been in the interest its work has aroused elsewhere on the subject, and in the compilation of a series of bulletins and technical articles which have been guideposts for other investigators and for commercial industry. For

[1] Dean, School of Engineering and Mines, University of Pittsburgh.

a number of years the Illinois laboratory was the only non-private laboratory devoting its attention to coal preparation; and its stimulus has been felt in every coal field of this country and abroad.

As an illustration, about fifteen years ago the writer was at a mining convention where the results of certain work of the Illinois laboratory were given. The audience consisted of four men. Two years ago at a mining convention at Cincinnati practically the same ground was covered in a paper, but to an audience of nearly 400 representing every part of the coal mining industry, all eager to hear and to discuss the paper. Professor Stoek's vision of the importance of coal preparation to the industry is being realized today by the commercial industry after the ups and downs of nearly twenty years. In the past year or two coal preparation plants have been installed having individual daily capacities of more than 8,000 tons, and subject to scientific and engineering control on a par with our most advanced industries. Compared with the crude rule-of-thumb coal preparation plants of twenty years ago, they represent a new era in coal preparation. The coal preparation laboratory at the University of Illinois cannot of course, take credit for this advance—it is due to the work of hundreds of men and to many organizations. However, in the compilation and issuing of data and by encouraging research and exact knowledge in the field of coal preparation, the University of Illinois laboratory has many times justified the vision of Dr. Stoek.

The term "coal preparation" generally means either the removal of impurities from the coal or the sizing of coal after mining and before utilization, or some combination of these distinct operations. Twenty years ago Illinois ranked first or second among all the states in the quantity of coal washed or prepared for the market by the removal of impurities. Today a number of districts have outstripped Illinois, not only in amount of coal cleaned, but in the introduction of improved methods. In actual screening and sizing of coal Illinois lead all the bituminous coal producing states and was second only to the Pennsylvania anthracite field. Today these processes have been widely copied and greatly improved. There is scarcely a bituminous coal producing district in the country that does not make a real effort to prepare its coal as to size and purity to meet the competitive market demands. It used to be considered that many coals were of such a nature that they were not benefited by the washing processes then in existence. Today with the modern coal jigs, with the various air separators, with the Chance sand process, The Rheolaveur process and with the adaption of the flotation and other processes to the coal cleaning problem, there is probably not a single coal containing its impurities in visible size that is not amenable to some one of these processes. In screening and sizing it seems that with the perfection of the modern shaking and vibrating screens the ultimate in this phase of preparation has been reached. In other words the technical progress in coal preparation during the past ten years has been so great that it will take the commercial industry many years to take full advantage of it. Technically many of the urgent problems of coal preparation have been solved; the near future demands more the working out of these processes to individual coals at a low enough cost so that the industry can afford to use them. Perhaps the exception to this rule is pulverized coal. More and more bituminous coal is pulverized to a powder before being burned. Theoretically this finely divided coal is in an ideal state for removal of impurities, inasmuch as the pulverization has freed the coal from the adhering impurities, but practically no process has been perfected which will clean this pulverized coal. Perhaps the solution lies in an air blast of varying velocity. At any rate the practical solution must be simple and cheap. The problem offers a real challenge in coal preparation.

Altogether, the most interesting developments today in coal preparation research are the following:

(1) Development of oil flotation of coal by the use of an alkaline circuit which permits the separation of the finely divided pyrite from the coal.

(2) Success in settling and clarifying the black water discharge from washeries by the use of starch and caustic soda.

(3) Realization that the removal of inerts or impurities in the fine sizes of coal has an important bearing in the physical structure of the resultant coke, especially in reduction in the so-called coke breeze.

RESEARCH FOR FUTURE NEEDS

Coal preparation in its broadest sense, is vastly wider in scope than sizing or even in taking out of the coal, visible impurities. It has been wisely remarked that coal has been discovered three times as follows:

First—as a raw fuel or source of heat.

Second—as a substance to be manufactured into coke and by-products.

Third—as a base for new chemical industries.

All of these certainly deal with coal preparation but in widely different senses. Let us consider them in order.

(1) *Coal as a raw fuel or source of heat.*—When we deal with coal as a raw fuel or source of heat we are concerned with cost, efficiency and general cleanliness. Education of the user as to relative cost and efficiency of prepared vs. unprepared coal is the most important step to promote the more general use of coal preparation plants. The worst feature of raw coal today, aside from smoke, is its general dirtiness. It is interesting to note that during the past year or two a number of coal companies and large numbers of retail dealers have adopted the plan of wetting down their coal with a solution of calcium chloride before shipping to the consumer. The plan

actually seems to keep down dust and dirt, presumably by taking advantage of the deliquescent property of calcium chloride. Perhaps further investigations might discover a more advantageous method of preventing dust, with a consequent increase in popularity of soft coal. It seems only a step further to add some substance to the raw coal which might prevent the formation of soot in chimneys. Apparently these are simple troubles and yet their solution would go far towards eliminating prejudice against soft coal.

(2) *Coal as a substance to be manufactured into coke and by-products.*—Some sixteen years ago I sat in a graduate class under Professor S. W. Parr at the University of Illinois and heard him foretell the early disappearance of the then common beehive coke oven, and improvements in the manufacture of by-product coke with its attendant by-products. Those of you who went through the Connellsville district of Pennsylvania a few years ago must have marveled, as I did, at the great tongues of flame and smoke leaping out of the hundreds of little beehive coke ovens. Today these ovens are deserted and grass-grown. In their place, at Clairton on the Monongahela River, stands the great by-product coke plant of the U. S. Steel Corporation where is treated one percent of the entire coal production of the world. Not only is the coke better than the old beehive coke, but in the by-products hundreds of chemicals are produced, ranging from road tar to aspirin. They are recovering from the coke oven gas, pure sulphur of such fineness that it is greatly demanded among orchardists as the most effective method of destroying fungus and other tree diseases. They are saving sodium thiocyanite which has been found to hasten greatly the germination of potatoes; and many other new by-products. But in these things we invade the province of the chemist. Of the utmost interest to coal preparation, however, is the problem of preparing, from the raw coal, a smokeless fuel. Why we of the twentieth century continue to accept the present smoke nuisance of our towns and cities is unanswerable. Certainly in a broad way we do not save money by present conditions. Nothing would popularize soft coal like making it smokeless and at the same time retaining its desirable burning qualities. No one has carried the work further than your own Professor Parr. The future, however, holds an unlimited opportunity to reduce research to practice in this field. It is not too much to prophesy in turn the introduction of a successor to the by-product oven which will entirely gasify the coal, thus completely converting coal to the ideal fuel without incidental production of coke.

Years ago the coal industry faced a crisis in competition from natural gas. Within a few years the natural gas resources near the large consuming centers were exhausted and coal again took command. Within the past three years the coal industry again faces this danger. Improvements in pipe manufacture and pipe line construction have made it possible to construct pipe lines for natural gas of a length and size hitherto considered impracticable. A natural-gas line has been finished recently from northern Louisiana to Atlanta, Georgia, and others ranging up to 900 miles in length are projected. To meet this competition is it not possible for the coal industry to pipe gas manufactured from coal over like distances, thus preparing the coal at the mine into gas, instead of shipping the coal? Already in New Haven, Connecticut, there is a coal-gas plant which supplies 65 per cent of all the gas used in the state and the gas is piped to Hartford, and other distant towns.

I am informed that at Clairton, Pennsylvania, the excess gas produced at the ovens at certain times of the year is pumped in great quantities down old exhausted natural gas wells near McKeesport. Later when this gas is withdrawn for use it is found to have changed in character, having lost some of its objectionable compounds and having absorbed enough methane from the strata so that its heating value is considerably greater than when pumped into the ground.

Will the coal industry slow down until the peak of natural-gas competition is passed, or will it be able through discovery and technical skill to meet the competition by preparing a suitable competitive fuel? Certainly the natural-gas industry is showing us how to ship heat units to the markets at a lesser cost than hauling them on the railroads.

(3) *Coal as a base for new chemical industries.*—Most of you know that in Germany and France they have succeeded in taking raw coal and preparing from it directly by hydrogenation a liquid which can be used as a substitute for gasoline and fuel oil. With the high cost of gasoline there they are actually selling the liquid coal as an auto fuel. My own feeling is that within a decade, we may be using larger supplies of our own coal to produce a similar fuel here. At any rate the discovery destroys any fear of an automobile fuel shortage.

Altogether I feel that the great future work to be done in coal preparation will be to develop the use of coal as a base for new industries, especially the chemical industries.

It is an interesting fact that nearly all the research in coal up to the present has tended to restrict rather than increase its production. We are informed that the modern central power station using coal produces a kilowatt with one-half the coal that it did ten years ago and that improvements in locomotive design reduces by 30 per cent the coal necessary to haul a ton of freight a mile. In preparation of coal in the by-product ovens more coke is obtained than in the old beehive and with the resulting gas this means that for each unit of heat used, less coal is required. All of these advances, although of general benefit to the public, do not promote the use of more coal.

The time is here to begin to devote our research to ends that will increase the uses of coal. I am informed that today, in every telephone transmitter are grains of coal which help to change the current as your voice changes. Compared to the tonnage of coal which may be used by further discoveries and improvements in the chemical industries, the quantity of coal needed for telephone receivers is ridicuously small, yet in this whole field of finding new uses for that wonderful complex organic chemical substance we call coal, lies the future prosperity of the coal industry.

THE AUTOMATIC STOKER FOR HEATING SERVICE USING ILLINOIS COAL

By A. C. Willard[1] and W. H. Severns[2]

INTRODUCTION

The development of automatic equipment and methods for heating buildings in the past few years has included practically every kind of fuel and type of burner. The final objectives in this development must provide for *economy* (including smokelessness), *comfort* and *convenience.* To entirely sacrifice the first of these objectives for the sake of the other two, is quite indefensible in any comprehensive and fundamental consideration of the problem. What is needed in the ultimate solution of this problem is automatic equipment which will burn the least expensive fuel in any locality with maximum efficiency and with practically as much comfort and convenience as can be secured with any other fuel, whether fired manually or automatically.

For the State of Illinois and much of the Midwest the least expensive fuel is the native bituminous coal. This fuel cannot be burned successfully in heating boilers and furnaces without smoke and with high efficiency by any method of hand firing unless more or less special equipment is installed. Moreover, even with special equipment installed, hand firing is inherently less convenient than any method of mechanical stoking. Mr. Victor J. Azbe[3] has proved that the correct principle for complete combustion with bituminous coal is that the distilled volatile gases must pass through the hot fuel bed and then be mixed with the air to complete the combustion practically at the surface of the fuel bed. This principle is satisfied by the down-draft furnace, the down-draft baffle, and the underfeed stoker, only the last of which can be regarded as automatic, and hence, effective in promoting comfort and convenience.

CHARACTERISTICS OF THE AUTOMATIC MECHANICAL COAL STOKER

The automatic mechanical coal stoker working on the underfeed principle will burn a less expensive fuel with greater economy (including smoke-

---

[1] Professor of Heating and Ventilation, and Head of Department of Mechanical Engineering, University of Illinois, Urbana.

[2] Associate Professor of Mechanical Engineering, University of Illinois, Urbana.

[3] Azbe, Victor J., Smokeless and Efficient Firing of Domestic Furnaces, Parts I and II. Transactions of the American Society of Mechanical Engineers, Fuels and Steam Power Division, January-April, 1928, page 175, and September-December, 1928, page 223.

lessness), and will at the same time provide fully as great comfort as can be secured with any other fuel fired automatically. It cannot be said that the stokers of the present day provide even approximately as much convenience as either oil or gas burners of the automatic type. They are, however, far more convenient to operate than any hand-fired heating unit, and the amount of attention which they require will be materially reduced as their development progresses. They satisfy the three objectives of *economy, comfort,* and *convenience* to a remarkable degree even in their present state of commercial development. For the central states of this country the less expensive fuels, as already noted, are the small sizes of Midwestern bituminous coals, which underlie much of this territory. These coals are relatively high in volatile matter, and if they are to be burned with the greatest efficiency, require careful combustion control. To secure such economy in combustion with the maximum of convenience and comfort the automatic mechanical underfeed stoker must be employed.

In the underfeed type of stoker, the volatilization takes place below the incandescent part of the fuel bed, and the unstable hydrocarbons are decomposed into fixed gases under the action of the hot carbon in the incandescent zone. This prevents the formation of smoke, which results from the partial combustion of the hydrocarbons in the presence of insufficient air at the surface of the fuel bed. A high temperature is maintained above the surface of the fuel bed, and the complete combustion of the fixed gases is accomplished by the admission of the proper amount of secondary air above the fire. The use of mechanical blowers with gates or orifices, instead of placing reliance on the uncertain relations existing between natural draft and the resistance of grates and fuel bed, permits very close control of the air required through the fuel bed. Since the amount of air forced through the fuel bed determines the rate of combustion, when stokers are used in connection with the heating units the speed of the blower should be governed by the outdoor weather conditions, thus regulating the rate of combustion to correspond to the weather. The speed of the coal feeding mechanism should then be accommodated to the rate of combustion. The completeness of combustion is determined largely by the amount of secondary air admitted above the fuel bed, and in order to reduce the excess air to a minimum this amount should be regulated to correspond with the combustion rate. It should vary with the speed of the blower and the rate of coal feed. As a rule, with proper operation, the loss due to combustible in the ash is small. Until it is fully appreciated that the proper control of an underfeed stoker depends on the correct regulation of both the primary and secondary air supply rather than on pounds of coal fed to the furnace, the operating adjustment of such a unit will be a matter of chance rather than intelligence.

The automatic mechanical stoker, moreover, is an apparatus requiring engineering knowledge rather than mechanical skill for its preliminary adjustment for proper combustion control. The advantages offered will, therefore, not be attained generally until the necessity for such knowledge is widely recognized, and until installation and adjustments are made under the competent direction of trained men instead of relying entirely on the services of skilled mechanics without the background of fundamental knowledge in the field of combustion. The mere presence of a stoker is not a guarantee of efficient performance and a poorly adjusted stoker may be no better than a manually operated plant.

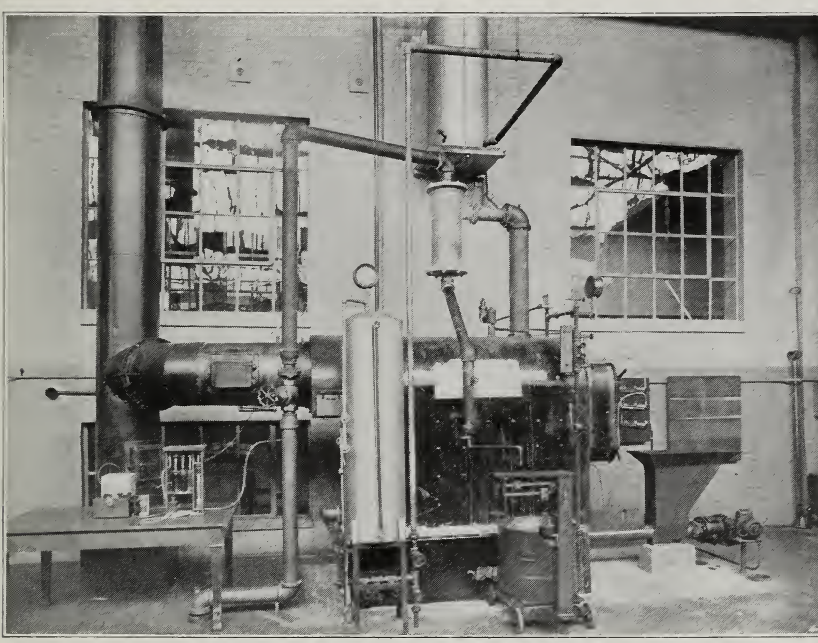


FIG. 13. Elevation view of stoker-boiler unit ready for test. (Picture taken before covering was applied to boiler, tanks and piping.)

PERFORMANCE TESTS OF AN AUTOMATIC STOKER AND STEAM HEATING BOILER UNIT

As an illustration of the performance of a modern stoker-boiler unit under actual operating conditions, such as exist in heating service using an inexpensive grade of Illinois bituminous coal, the following results (Table 4 and Fig. 14) from a series of tests just completed at the University of Illinois are presented. These tests are preliminary to a further and much more complete study of stoker-boiler unit performance.

The testing plant is shown (before boiler and pipe covering was applied) in Figure 13. The boiler was a standard commercial welded steel firebox type with a double pass of fire tubes. The principal dimensions taken from manufacturer's data were:

Heating surface = 262 sq. ft. = 241 sq. ft. (using fire surface).
Grate surface = 11.6 sq. ft.
Ratio H.S./G.S. = 22.6.
Tubes all 3 in. outside diameter.
First pass 21 tubes 4 ft. 7 in. long.
Second pass 24 tubes 6 ft. 4 in. long.
Length of firebox = 70.0 in.
Width of firebox = 30.0 in.
Height of firebox = 26.0 in.
Volume of furnace and combustion chamber above grates, apx.
20 + 10 = 30 cu. ft.
Height water line = 69.0 in.
Smoke collar = 22 in. diameter.
Stack steel = 20 in. diameter and 44 ft. above grate.
Rating in sq. ft. of direct steam radiation of 240 B.t.u. value = 3630.

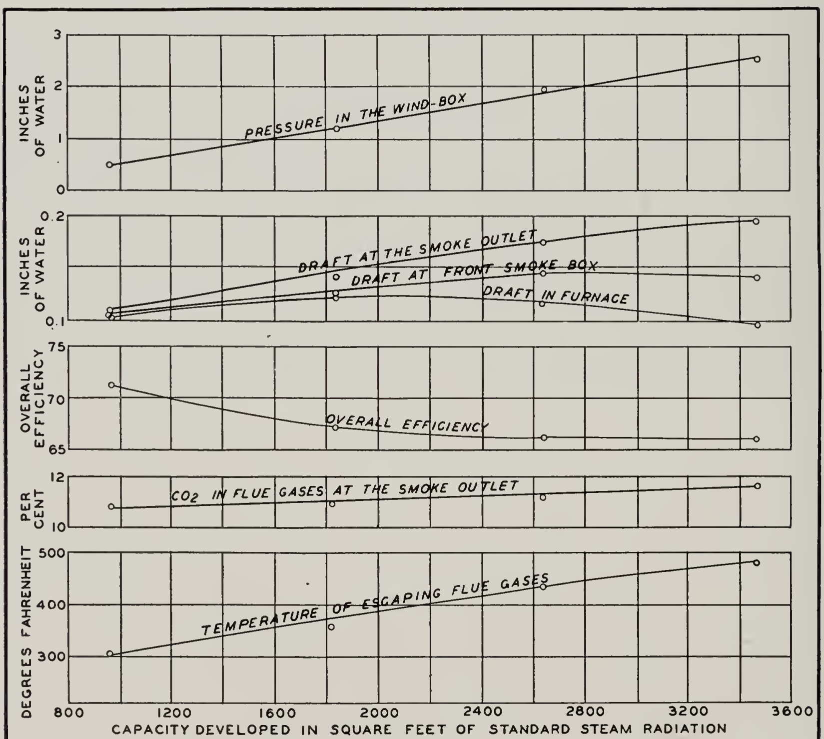


Fig. 14. Graph showing results of tests of a stoker-fired heating boiler at the University of Illinois, Urbana.

The stoker was also a standard commercial screw-feed type with separate motor drive for coal feed and fan. The coal feed could be regulated by hand control of motor speed, as well as by an on-and-off pressure stat. The coal tube was 4 inches in diameter inside and the coal retort was 7 by 17 inches just below tuyeres. Coal screw 3¾ inches diameter maximum at entrance to retort and 2⅞ inches diameter at hopper; driven by ¼ horsepower single phase brush shifting motor, 220 volts. Capacity at full speed approximately 150 pounds of coal per hour. Maximum wind box pressure, 3.2 inches, water gage and fan driven by ½ horsepower single phase constant speed motor. The local power company supplies current for small stoker motors at 7 cents per kilowatt-hour.

The fuel used was 1½ inch screenings of the analysis shown in Table 4, and cost $3.60 per ton in the bin.

CONCLUSIONS

Based on the stoker-boiler unit tested, the results (Table 4) indicate that:

(1) A less expensive grade of Illinois coal (costing $3.60 per ton in the bin) may be burned without visible smoke and with good efficiency, ranging from 65 to 70 per cent. In the opinion of the authors, the principal saving from the use of automatic coal stokers will result from the use of a less expensive fuel, burned efficiently and smokelessly.

(2) The stoker will perform automatically for considerable periods of time and maintain a practically constant steam pressure with a maximum variation of ¾ pound above or below normal.

(3) The attention required in heating service will depend on the weather conditions and the frequency with which the hopper must be refilled or the fire cleaned, at which time ash and clinker is also removed. In severe weather, the attention must be more frequent than in mild weather.

(4) To what extent labor costs may be reduced by the installation of a stoker was not within the province of the present tests. It is certain, however, that a stoker will relieve the attendant for considerable periods of time, so that more stoker-fired plants may be operated by one man or he may have more time for other duties than with a hand-fired plant.

(5) It is rather difficult to so adjust both primary and secondary air that the coal feed and air supply will be perfectly synchronized. As a result of failure to synchronize the air supply and coal feed, either coal may accumulate gradually in the fire box or the fire may burn thin.

(6) The relative amounts of primary and secondary air must be varied with the rate at which coal is fed and better and more accurate air control devices or equipment are desirable if not essential.

(7) The rate at which coal is fed has very little connection with the rate of combustion in "on and off" operation. Only when the stoker runs continuously will rate of coal feed be the same as the rate of combustion.

(8) Average CO_2 readings and average flue gas temperatures mean very little in these tests with "on and off" operation even though "time on" and "time off" is accurately determined. Single CO_2 readings are of the greatest value, however, in adjusting the primary and secondary air to give best results with different coals or with different rates of feed of the same coal.

(9) It is practically impossible to make an accurate "heat balance" with a stoker operating on an "on and off" control. This can only be done when stoker operates nearly continuously, which means that at less than full load capacities the rate of coal feed must be reduced and the air supply readjusted accordingly to give continuous operation.

(10) Special consideration should be given to the undesirability of creating hopper smoke, especially with a nearly empty hopper and with more or less clinker in the furnace.

FUTURE INVESTIGATION OF STOKER-BOILER UNITS

(1) A carefully planned program of tests should be conducted to determine the best method of stoker control for heating service. At least two general methods deserve careful study.

One provides a constant, maximum rate of coal feed sufficient to take care of the full load requirements. In mild weather, this same rate of coal feed is used but the stoker is "off" a much greater proportion of the time. The air supply adjustment is kept constant.

The other method provides for a variable rate of coal feed with corresponding adjustment of the air supply. In mild weather, the lower rates of coal feed are used and the stoker is "on" about the same length of time regardless of the weather. This method would appear to be more efficient, but would demand more attention and skill on the part of the attendant.

(2) Two series of tests using different coals as well as different sizes of the same coal should be conducted to determine whether or not higher efficiencies might justify the use of somewhat more expensive coals. Material variations in heat value, volatile matter and ash content should be the basis for selecting these different coals, to give as wide a spread in coal characteristics as possible.

(3) Another series of tests should be undertaken to determine the effect and importance of furnace and combustion chamber space on stoker operation, at both high and low loads or rates of combustion. There is no doubt that the ratio of furnace and combustion chamber volume to pounds of coal burned per hour has an effect on both efficiency and capacity of a stoker-boiler unit.

TABLE 4

Department of Mechanical Engineering
University of Illinois

Mechanical Engineering Laboratory

RESULT SHEET

STEEL BOILER AND AUTOMATIC COAL STOKER

(For dimension data see text)

Also see Fig. 13 for elevation view of stoker-boiler unit as tested

No.	Name of Item (With Units)	Trial Number 1	2	3	4
1.	Date of test	April 17 1930	April 18 1930	April 22 1930	April 23 1930
2.	Duration of test, hrs	6	7	8.25	9
3.	Kind of coal	Illinois Coal			
4.	Size of coal	1½-inch Screenings			
5.	Proximate analysis of coal as fired:				
	Fixed Carbon, per cent	43.44	42.69	42.12	42.56
	Volatile Matter, per cent	37.02	36.38	35.91	36.28
	Moisture, per cent	7.10	8.70	9.89	8.98
	Ash, per cent	12.44	12.23	12.08	12.18
	Sulphur, separately det.	4.42	4.35	4.29	4.33
6.	Calorific value of coal as fired by oxygen bomb calorimeter, B.t.u. per lb.	11,133	11,036	10,892	11,002
7.	Calorific value dry coal, B.t.u. per lb.	12,088	12,088	12,088	12,088
8.	Ultimate analysis of coal as fired:				
	Carbon, per cent	60.63	59.58	58.78	59.40
	Hydrogen, per cent	4.62	4.53	4.48	4.52
	Oxygen, per cent	8.73	8.58	8.47	8.56
	Nitrogen, per cent	2.06	2.03	2.01	2.03
	Sulphur, per cent	4.42	4.35	4.29	4.33
	Moisture, per cent	7.10	8.70	9.89	8.98
	Ash, per cent	12.44	12.23	12.08	12.18
9.	Steam pressure, lb. sq. in. gage	3.14	2.76	2.83	3.2
10,	Barometer, in. Hg	29.26	29.51	29.54	29.46
11.	Steam pressure, lb. sq. in. abs.	17.50	17.30	17.33	17.65
12.	Pressure in wind box, in. water	2.58	1.92	1.20	0.56
13.	Draft in furnace, in. water	0.097	0.115	0.123	0.102
14.	Draft in front smoke box, in. water	0.135	0.141	0.124	0.104

TABLE 4 *(Continued)*

No.	Name of Item (With Units)	Trial Number 1	2	3	4
15.	Draft at smoke outlet, in. water	0.196	0.179	0.143	0.106
16.	Temperature outside air, deg.F.	65.9	47.4	46.4	49.3
17.	Temperature air of room, deg. F.	85.7	81.0	75.5	77.5
18.	Temperature gases at smoke outlet, deg. F	475	432	357	303
19.	Temperature steam leaving boiler, deg. F	220.9	220.7	220.5	221.1
20.	Temperature feedwater at measuring tank, deg. F	205.1	201.3	195.6	182.9
21.	Total inches of water fed	737.63	647.75	525.62	296.92
22.	Total weight of water, lb.	5119	4502	3658	2078
23.	Total weight of water from separator, lb.	20	8.25	8.5	8.0
	(Note that heat loss from separator accounts for about 0.9 lb. of condensate per hour.)				
24.	Quality of steam	0.997	1.00	1.00	1.00
25.	Total factor of evaporation	1.007	1.014	1.020	1.033
26.	Total equivalent evaporation, lb.	5154	4570	3733	2146
27.	Total weight of coal fired, lb.	683	610.5	494.5	268
28.	Total weight of ash and refuse, lb.	51.75	62.5	51.0	22.75
29.	Analysis of ash and refuse:				
	Moisture, per cent	0.16	0.07	0.03	0.04
	Volatile matter, per cent	0.00	0.00	0.00	0.00
	Fixed carbon, per cent	7.86	4.46	5.15	3.19
	Earthy matter, per cent	91.98	95.47	94.82	96.87
30.	Stoker in operation, time per cent	....	....	....	....
	(Note stoker operated with "on and off" control for variable periods of time, and also stoker operated at variable rates of feed during the "on" periods, depending on operating load.)				
31.	Interval between raking fire, mins.	71.2	46.0	53.0	66
32.	Interval between cleaning fire, hours	6	3.5	8	9
33.	Average height water in gage glass, in.	0.77	0.78	0.75	0.73
34.	Equiv. evap. per hour, lb.	859.1	653	453	238.5
35.	Coal fired per hour, lb.	113.8	87.2	60.0	29.8
36.	Pounds of coal, per hour, per cu. ft. of furnace and combustion chamber volume	3.79	2.90	2.00	0.99

Table 4 *(Continued)*

No.	Name of Item (With Units)	Trial Number 1	2	3	4
37.	Equiv. evap. per sq. ft. of heating surface per hour, lb....	3.56	2.71	1.88	0.99
38.	Equiv. evap. per lb. of coal fired, lb.	7.55	7.49	7.55	8.07
39.	Capacity developed, sq. ft. rad.	3475	2643	1832	962
40.	Percentage of capacity developed	95.7	72.8	50.4	26.5
41.	Efficiency of boiler with stoker, per cent	65.9	66.0	67.3	71.2
42.	Flue gas analysis, stoker in operation:				
	(Note that with "on and off" operation the stoker *average* flue gas analyses mean very little. The CO_2 values are given only for periods when the stoker was "on." In the last test, the CO_2 for stoker "on" and "off" dropped to 8.1 per cent. Similar reductions were observed in the first three tests for "on" and "off" operation.)				
	Carbon dioxide, per cent..	11.5	11.1	10.8	10.8
	Oxygen, per cent.........	7.3	8.4	9.1	9.1
	Carbon monoxide, per cent	0.4	0.1	0.0	0.0
	Hydrogen, per cent.......	0.15	0.1	0.0	0.0
	Nitrogen, per cent........	80.65	80.3	80.0	80.1
43.	Smoke data:				
	Periodic and regular observations of the smoker were not taken. In general, smoke of number 1 and 2 grade appeared only when the fire was disturbed or when the stoker cut into operation. For the major portion of the time of observations the stack was smokeless or very nearly smokeless.				
44.	Average kw. per hour to operate	0.433	0.51	0.357	0.21
	(Note smaller value in column 1 at full load is due to better position of motor brushes with motor operating at full speed.)				
45.	Cost per hour to operate stoker and fan unit at 7c per kw. hr., cents per hour.........	3.0	3.6	2.5	1.5

Also see Fig. 14 for graphical log of test.

Intermission

Continuation of Symposium

Dr. H. Foster Bain, *Presiding*

UTILIZATION OF BASIC INFORMATION IN FUTURE MARKET PRACTICE

By F. C. Honnold[1]

THE PRESENT MARKET SITUATION

None but those actively participating in the production, sale, transport and final distribution of Illinois coal are apt to realize the extent and variety of the embarrassment that confronts its operators and miners, or that of individuals and concerns who are or have been the consumers of Illinois coal. A very brief presentation of a few outstanding factors that have brought this condition about seems essential in order that what is said later on may be better understood.

The Competitive Situation

The Chicago switching district is the largest coal-consuming center in the world. Forty per cent or more of the total railroad mileage of the United States centers there. As among all cities of first magnitude, it is also nearest the exact center of the country's manufacturing industry, agricultural production, and general population (Fig. 15).

Because of these facts probably no like area anywhere in the country produces and ships either so much or so wide a variety of manufactured products as moves out of that section including Illinois, southern Wisconsin, the eastern half of Iowa and that part of Missouri north of a line from Kansas City to St. Louis. It is very easy to understand why competition among fuels of all kinds and from an extreme number of points of origin should exist constantly within this outlined territory, which constitutes the primary market for our coal.

Labor

During the period from 1920 to the fall of 1928, the labor situation in the Illinois coal industry was at all times a serious handicap. Based on the present wage contract, expiring March 31st, 1932, our position would appear much improved and definitely more promising, although disturbing confusion

[1] Secretary-Treasurer, Illinois Coal Bureau, Chicago, Illinois.

still prevails. We are hopeful that labor may in the early future become and thereafter continue more dependable.

The experience of Illinois miners during recent years has made them realize that if they are to succeed, they must recognize and fully discharge their direct obligation to the public whom in reality they serve. They are now aware that the erratic and uncertain operation of Illinois mines, because of local and state-wide strikes, has hurt them as directly as anyone else, possibly more so. They also now know that the long continued demand for an impossible wage rate and restrictive operating practices made it increasingly difficult, to a point of ultimate impossibility, for Illinois coal to compete in the markets.

Their change of viewpoint can be understood when it is remembered that 87 cents of every dollar spent in the production of a ton of coal, at shaft mines, goes directly to labor, either in the form of wages, dues paid to their union, or amounts expended in their behalf under the Compensation Act. In few if any other industries does labor participate so directly in the sale price of the raw commodity at the point of delivery.

Illinois Coal Producing Companies

Regardless of the fact that those operators producing and marketing the larger volume of Illinois coal are already providing a very superior product, as to removal of impurities and careful preparation and sizing of the coal, they realize the importance of maintaining always the highest possible standards of practice in these, as well as in other, respects, in order that the quality of their coal may be maintained at a high level. To this they commit themselves and will in the future, as in the past, seek, through co-operation with their miners and by every means, to maintain a high standard and to be constantly on the lookout for new and better ways of discharging their function as dependable service agents, which in reality is an exact definition of their status. The bulk of the money paid by coal consumers—at the average destination where final delivery is made in car lots—goes to the miner for wages and to the railroads for freight. It is a very rare year when a producing coal company receives for its service as much as five cents out of each dollar paid by the ultimate destination car-lot buyer. Further, it should not be forgotten that an average of about 40 per cent of the total annual production at an Illinois mine fails to return even its cost. This applies to all coal passing through a two-inch, round, screen opening.

Freight Rates and Transportation

Although this is not a subject to be dwelt upon in detail at a conference of this character, some brief mention of this important factor in the present situation is essential. (1) That the cost of coal transportation, considering an average of all destinations, exceeds the price paid for coal at the mine,

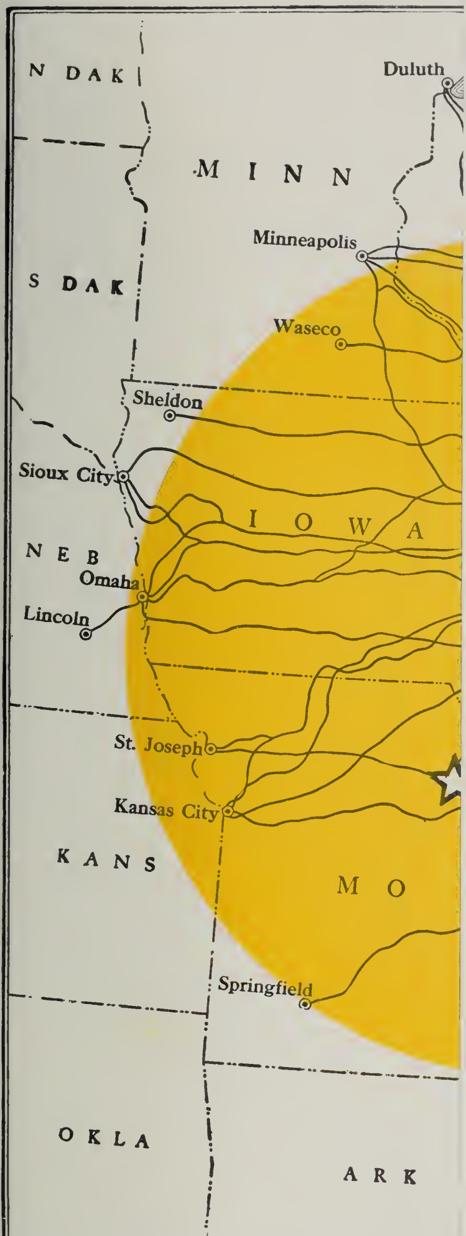


FIG. 15. The unmined coal reserves in
hundreds of years.

In the immediately adjoining states of
ulation, marked by a triangle; and the center

The strategic importance of this section

Passenger schedules on railroads entering
working time.

The black lines represent railroads with

Forty per cent of the Class 1 railroad

should always be held carefully in mind. (2) The further coal is hauled, the higher its cost, and there are no heat units in a freight bill.

These two facts make clear that discriminatory or prejudicial rates as between producing fields may become destructive and produce disastrous results to the welfare of any state whose own coal production is substantial.

Illinois coal producers, Illinois miners, and a very large part if not a majority of the consumers of Illinois coal feel strongly that the changes and readjustments of freight rates affecting Illinois coal have since the war been inequitable and more or less unjust. At all events they have been the direct occasion of a very large loss of tonnage that might have moved from Illinois mines.

The grant (in 1924), under authorization of the Interstate Commerce Commission, of joint through rates, permitting a wide variety of eastern non-union coal to move to an extremely wide western destination area, extending well beyond the Mississippi River, might seem to be in very definite violation of economic propriety closely approaching a serious discrimination between coal producing states.

We shall not dwell longer on this subject because certain very important cases bearing on this precise situation, which we feel so seriously affects the welfare of Illinois, go to hearing early in June and will probably at that time be the subject of sufficient general publicity to advise all of those who are directly interested.

Present Situation

The present situation in the Illinois coal industry is one of revolutionary, social and economic readjustment. Such a change always comes slowly. This is due to the fact that the great majority of the people do not take seriously and consequently know little about those larger economic questions that often so vitally affect their own immediate welfare.

Figure 15 portrays the geographic situation of the Illinois coal field with regard to lines of transportation and the country's centers of (1) manufacture, (2) population, and (3) agriculture.

There must be widespread reliable information that will stimulate intelligent public thought and careful consideration in and out of Illinois, with respect to possible serious future consequences that may develop from present careless neglect of the welfare of the coal producing industry in Illinois. For our purposes we are perfectly willing to accept the estimate of Mr. Garcia as to the amount of the unmined coal reserves still available in our state. The area in which it is found (42,000 sq. miles) is larger than that in any other state. That this volume of coal is near by and accessible on short freight hauls to what will undoubtedly be the largest coal market and general trade area of the country for many years to come, guarantees a dependable fuel supply for a good many hundred years. This great treasure also can, when properly handled, and with very few exceptions, *do all that any fuel* *can do* and at substantially less cost. It is for those reasons by far the most valuable resource the state has. Coal gone cannot be replaced.

This near-by coal reserve deserves the protection of every mid-western consumer of this coal against every unwarranted competitive assault.

It is the settled belief of Illinois coal producers, following a very careful survey and study of all other competing coal producing districts, that in no other state, taken in its entirety and the average coal quality considered, has there been during so long a period such positive and definite elimination and restriction, both in the number of operating mines and the number of workmen thrown into idleness during the past decade.

Enough has been said here to adequately outline the present status and to suggest why we at this time urge so strongly the mutual participation and assistance of all parties concerned, as a simple matter of enlightened self interest.

FUTURE MARKET PRACTICE

With such prelude we come to the direct consideration of those things suggested by the title, "Utilization of Basic Information in Future Market Practice." Listed below are twelve items on which we shall require continuing information and effort. These have not been set forth in the order of their importance as each of them will vary from time to time in importance, but each alike should have constant attention.

1. Labor.
2. Intelligent constructive activities by producing companies.
3. Transportation conditions, rates and other incidental factors.
4. Awakening education and fact data to direct coal users.
5. Smoke abatement.
6. Combustion engineers.
7. Increase of combustion engineer personnel and service.
8. Constant active effort by universities and technical high schools, through research, testing laboratories and shops, along practical lines.
9. Informative, instructive bulletins of direct appeal to home owners.
10. Close cooperation along all practical lines of community interest with the makers of all types and kinds of approved or promising coal burning equipment, consuming either large or small annual volume of Illinois coal.
11. Continued publicity by each of the above specified groups, as well as closely cooperative and synchronized effort between related groups.
12. Annual conference in which all midwestern interests should participate for the purpose of making careful presentation and canvass, and of determining as far as possible proved and demonstrated facts of the preceding year and outlining activities for the succeeding year. All friction between such groups should be eliminated and the single

purpose constantly held in mind that we all alike seek to promote and guarantee the efficient and economical use of Illinois coal to the greatest possible benefit of the miners, the distributors and the consumers—all for the welfare of this midwestern section of the country which is our home, not forgetting that "where the home is the heart is" (or should be).

The first three of these listed subjects have already been sufficiently discussed, or if not, and having, after the fashion of a Congressman "leave to print," may be elaborated in a bulletin which it is hoped will be issued promptly. The next seven items are those in which the University of Illinois can be directly and indirectly very helpful, and in cooperating in the work will render a direct and highly important service to the public of Illinois, which supports this institution.

Awakening and Education of the Public

Much effort through every possible agency can and should be made to inform the public intelligently and honestly of exact facts. A large part of humanity, possibly a majority, are inclined "to follow the leader." Numerous illustrations of this fact have gradually developed with respect to the use of Illinois coal. One of these was and still is a growing antagonism to the purchase of our coal because of the erratic operation of our mines, the causes of which have been previously mentioned. The long continued relatively high price of Illinois coal has been another factor.

The public is not concerned with the wage rates paid to Illinois union miners, or with the fact that on four different occasions Illinois wage contracts were negotiated by the government, reaching a maximum peak eighteen months after the armistice; nor that this post-war high wage rate was paid continuously for almost nine years thereafter. The last three years it was paid only in Illinois, almost every other unionized district having meanwhile entirely or in part abandoned or in some way divorced itself from the miners' union. Illinois laws deny its coal operators any such privilege.

Neither is the coal consuming public at all concerned, except as it is reflected in their coal cost, with the fact that freight rates have advanced very substantially and still remain to the great majority of destinations 75 per cent or more above pre-war levels.

Whatever the cause may be that raises the price of any commodity or article, there is an instant effort to economize or to substitute something else. Thus with the price of Illinois coal held for a long period above any previous price levels, and with the non-union sections of the country able promptly to reduce their mine production cost 50 to 75 cents or more per ton, the consuming public, regardless of the higher freight rate on eastern coal, grew more and more antagonistic to our Illinois product.

It was believed that regularity of Illinois mine operation could not be relied upon but that regular and prompt service could be provided from eastern coal producing districts. Many large coal consumers either did not desire to or could not store coal. They also felt, as a part of their grievance against the Illinois coal industry, that their being compelled to store large amounts of coal while mines were idle on account of strikes was unfair, unjust, and should not be tolerated. Meanwhile, railroad service becoming more and more adequate, it was figured that regular receipt of an adequate supply largely if not entirely justified their payment of additional transportation cost through and by which they could either eliminate or greatly reduce storage and incidentally register their dissatisfaction.

The general public of this midwest section should know and fully understand, each coal consumer for himself, the lack of justification for going abroad for his coal requirements and that, in "following the leader," he, as a consumer, as well as the community and state in which he lives, suffers a direct economic loss as a result of his lack of information or misapprehension of facts.

Smoke Abatement

Smoke abatement has been another very large factor, which in connection with public indifference, has made publicity and an educational program not only desirable but imperative. There is a growing demand for the elimination of smoke. That Illinois coal shall be successfully and economically consumed and without making smoke, must and can be guaranteed. It is because the coal from our state cannot in the ordinary practice of the great majority of consumers, be hand-fired without the development of smoke, that so large an increase in the volume of eastern coal has moved into this state during the past half dozen years.

After the fashion that distance lends enchantment, and that the cow will risk the laceration of her neck getting her head through the barbwire to eat grass no better than that in her own pasture, the belief is very widely held that any or all eastern coals can in the same careless fashion of many years back be burned smokelessly. This is not the fact. There must be exercised as much selective care in the purchase of eastern coal with respect to its being smokeless or having exceptional heat value, low ash and low sulphur, as should be exercised in the purchase of coal from any other source.

To secure positive, certain value and permanent results in the way of maximum fuel economy, with need for less labor and permitting increased mechanical control and the elimination of smoke, every coal consumer should at once carefully consider the benefit he can derive from reconditioning his plant. In the development of power or heat and where the factor of special use and requirement does not enter, there is no doubt that the nearby coals are the best fuel for the people in this midwest section. A majority of the larger steam coal users of Illinois have known this for many years; it is the smaller users whose requirements range from 10 to 200 tons a year who are not aware of this fact. A very large amount if not a majority of eastern coal moving into the Illinois and adjacent areas west, occasions many direct and indirect losses to consumers and to the communities into which it moves. Whenever and wherever a fuel consumer can replace or recondition his equipment for its proper combustion, Illinois coal will make possible a minimum saving of from 50 to 75 cents per ton as compared with any eastern coal. In addition such a consumer will have established fuel economy through the use of nearby, short-haul coal and will also have done his bit in the elimination of smoke.

Ashes and other non-combustibles present in all coal must be reckoned with, however or whatever coal or coke is burned. The number of people willing to provide necessary attention to meet and dispose of this handicap of coal will outnumber those who prefer to burn high-cost smokeless fuels (gas, oil, anthracite and coke) by several hundred to one. It is logical to conclude, based on the natural desire to save money, that this larger percentage of people will not shrink from the use of nearby coal, even though it involves some attending effort, if through the use of small stokers they can eliminate smoke, be provided with automatic firing and some dependable form of heat control, with longer periods between firing and with the removal of ash made easy.

Combustion Engineers and Other Personnel

To accomplish anticipated results means we must have an increasing demand for the advice and service of combustion engineers. The new day for increasing successful and economical use of the mid-volatile coal of Illinois will require widespread diffusion to the public of certain simple but vital facts with respect to the proper and intelligent use of coal.

The American public must be shown. What they can see, and watch in action most quickly engages and stimulates their thoughts and ultimate decisions. Those, therefore, who will read, must be provided written text. Those who do not or will not read must be shown by exhibitions or individual demonstrations.

It is for this reason, that with the development of automatically controlled, mechanical coal-feeding units, there will be required the earlist possible training by our universities and other competent agencies, of a rapidly increasing personnel. The genius who may devise an instrument or the earnest student who may discover a fact or principle, renders very high service to humanity but such benefits could never be brought finally to the public without the many thousands of people who constitute the well organized personnel of any industry exploiting such idea or device.

It also seems desirable that we shall to the greatest possible extent avoid the mistakes and errors that occurred to the very great detriment of the oil burner manufacturers when their devices were first offered.

It seems most desirable to project our work after the fashion of a clinic rather than an experiment. Experimentation after installation, at the expense of the public, should be to the greatest possible extent avoided.

The Task of Universities and Technical Schools

We must, therefore, at the outset, look to our universities, technical schools, research laboratories, operating exhibits, and other helpful agencies for assistance towards the development of this required and adequate personnel. Technical research, other than previous findings already available, probably will be of least essential value to us in meeting our immediate needs. Such research should be of substantial value later on and on that account should be encouraged but only after careful determination of objectives.

Extensive research and experimental plants have already proved quite definitely that many suggested and theoretical methods for the transformation and use of coal, as well as its cheaper transportation from point to point, are for future use, being impractical for present utilization because of extreme cost of installation and operation, except in very occasional instances.

Present developed information with respect to vital and essential combustion principles and general practices, together with a comforting number of engineers skilled along these lines, must be our first line of defense with an increasing personnel coming along, varying somewhat in the precise character of their training. Some of them must be recruited as rapidly as possible, particularly for early utilization as service men, through short courses both at our universities and technical high schools.

For this reason whatever attempts we shall make now should be prompt and definitely practical. They should contemplate the best possible utilization of Illinois raw coal, and facts along this line should be made available to the coal consuming public at the earliest possible moment. This means that our thought runs particularly to the present helpfulness of mechanical and combusion engineers, in and out of colleges, through their shops and testing laboratories, utilizing to the best advantage our present accumulated fact data on proved combustion practice and the maximum serviceability and economy of our own nearby coal, for the present in its raw state.

Cooperation with Makers of All Types and Kinds of Approved Coal Burning Equipment

That this is important and desirable goes without saying. The producers of coal or other raw commodities are in very few instances in position financially or otherwise to provide other than delivery of product at their own plants. They cannot manufacture, install devices for use, or instruct directly as to proper utilization.

They can, however, and should cooperate with the above named intermediaries who stand between them and the ultimate consumer because each of them constitutes a very important service element and each should understand fully the problem of the other.

Many prospective stoker concerns, in undertaking to exploit what seems to them "the last word" in the way of mechanical sufficiency, often will find later on that they did not fully understand or anticipate the difficulties to be met, in design, in finance, or in salesmanship and after more or less brief struggle, will be eliminated by the competition of more effective units. With proper cooperative arrangement, every individual or concern contemplating the exploitation of any device might be assured an opportunity of having his offering carefully studied and considered by neutral counsel who will have no competitive reason for neglecting or failing to recognize any merit his proposed enterprise may possess. If worth while, what he offers will receive its due share of recommendation and if unworthy or inadequate, he will from such counsel probably be protected against unnecessary loss. In either event, the public will be greatly benefited.

Publicity to be Synchronized

Publicity is such a widely diversified and highly specialized factor in business that any attempt to discuss its various ramifications as they might apply to the welfare of the various groups herein concerned, is not only folly but impossible.

The single thought here presented for careful consideration is the very great desirability of synchronization of thought, that all statements made shall be facts, on which policy alone the publicity of all of us will be solidly based.

There is a constant recurring tendency to overstate facts and to guarantee beyond proved possibility to perform. Such a procedure is very apt to bring about early failure which not only eliminates the offending individual but prejudices an entire enterprise such as that upon which we now are embarking. There are ample proved certainties as to what can be done with Illinois coal, used in a properly designed and serviced, mechanically-fired device, to fully justify the public adoption of such new methods for the use of nearby coal. Those, therefore, who seek to accelerate sale by exaggeration or by vague and unwarrantable statements, become at once an outstanding menace, hence the suggestion of synchronization.

Annual Conferences

There can be little amplification of what has been prevoiusly stated. A properly conducted conference can be made very inspiring and of definite potential value. There are many who work panistakingly, alone and with great care, stimulated by the hope that they may learn some new fact or discover some new device or method that will benefit the public through some industry and its allied crafts. They labor with a germinating idea and possibly carry their findings to kindred spirits for incidental counsel, advice and suggestions until finally something definitely worth while, even if not perfect, is evolved. Periodic conferences where their several offerings of partial or total accomplishment may be submitted for discussion by or approval of their equals, naturally result in advancement in all lines of work and it is thus that our country as a whole has made such giant strides in the advancement of its general welfare, with an increased feeling of security, comfort, contentment and greatly enlarged enrichment of life.

THE CHEMISTRY OF ILLINOIS COAL

A Review and a Forecast

By S. W. Parr[1]

Without question, the boundary of the State of Illinois circumscribes the greatest coal deposit in the world.

By way of very brief retrospect, it is appropriate that a few milestones or "high spots" along the way be pointed out.

First—and without elaboration, for it needs none, let us quote from the first paragraph of the admirable bulletin by A. Bement[2] as follows:

"It was in Illinois that the first recorded discovery of coal was made on the North American continent."

Second—from the bulletins and publications of the Survey, and also from the estimates contained in the Report of the 12th International Geological Congress—Canada, 1913—it may be seen that this Illinois area, extending slightly over into Indiana and into Western Kentucky, exceeds nearly three times the total area of all Europe, including that of the British Isles, and further, that the tonnage reserve credited to this Illinois area exceeds by one-third the total tonnage credited to Pennsylvania and West Virginia, combined.

Third—no serious study of a chemical nature had been made on the coals of Illinois previous to the year 1904. A small amount of chemical information was in existence previous to that date but it was entirely analytical in character and gave no information other than to tell the percentage of moisture, ash, volatile matter, fixed carbon and sulphur present in the coal. It is true that W. D. Rudy, a senior student in chemistry at the University, collected face samples from mines at Bloomington, Carbondale, Duquoin, and Mt. Carbon, Jackson County, upon which, as a topic for his Bachelor's thesis, he made ultimate analyses, but, so far as the record goes, the purpose of the study was completed when percentage values for the elemental constituents were obtained.

It will be seen, therefore, that up to almost exactly twenty-five years ago there had been no investigational work whatever done on Illinois coals. You will see from this somewhat sweeping statement, that I have relegated purely analytical processes and results to a place outside the realm of investigation. This is true in the main, for analytical values for the most part

[1] Professor Emeritus of Applied Chemistry, University of Illinois, Urbana.
[2] Bement, A., Illinois Coal. Illinois State Geol. Survey Bull. 56, 1929.

are required as operating data by the engineer, who must know the percentage of combustible and non-combustible material, such as ash and moisture, which is delivered to him for the production of power. It does not apply, however, to investigations seeking to improve and make more accurate the processes of analysis.

So, I still maintain that the securing of data by chemical analysis is not chemical research on coal.

I recall, at this time, with no little interest, a conversation with Professor Breckenridge, Dean of the College of Engingeering, the date being a little over twenty-five years ago. He said, in effect:

"Let us assemble all the known analytical data on Illinois coals, from whatever source, which seems to be reliable, publish the same, putting it all behind us, then begin on a new and clean slate."

I think neither of us quite realized the significance of that program. As a matter of fact it marked the line of differentiation between purely analytical processes for furnishing operating data on the one hand, and on the other, the intensive study of fundamental problems relating to the constitution of coal, which was inaugurated soon after the organization of the Illinois State Geological Survey.

As evidence that this program proposed by Professor Breckenridge was adhered to, let me call your attention to the first published report on Illinois coal, which contained all of the analytical data available at the time. It was published under the title of "The Chemical Analysis and Heating Value of Illinois Coal," and, because of lack of funds or more correctly speaking, for lack of any definitely organized body formally backing such activity, the report was obliged to be published outside of the University. This was accomplished through the courtesy of the Illinois Bureau of Labor Statistics, the material being published as part of their report for 1902, a thousand reprints being supplied as "separates" for use of the University departments interested.

Fourth—as a fourth observation of a retrospective type, I desire to note the fact that, beginning with the year 1904, coal studies of a chemical nature were inaugurated which had an altogether different objective, seeking to develop information of a fundamental sort whereby a better understanding could be had of the properties, the behavior, and the functioning under all circumstances, of coal, leading also, ultimately, to a knowledge of the constitution of this very complex material, and that in a way which could not even remotely be furnished by the usual analytical processes.

In that year, a chemical study of Illinois coals was prepared for distribution through the Illinois Exhibit, at the St. Louis Exposition. This was also published as the University of Illinois Studies, No. 7. This study, in addition to recounting some improvements in analytical methods, made special reference to an attempt to determine the behavior of sulphur in the process of coal decomposition by heat and also gave a very considerable account of new methods proposed for the determination of calorific values.

At this same date, 1904, there was inaugurated at the St. Louis Exposition an elaborate study, chiefly of an analytical nature, of all American coals, seeking an improvement and standardization of methods of analysis, and from this beginning, inaugurated under the auspices of the U. S. Geological Survey, has developed the mass of analytical and investigational data which has given the work of this sort a paramount place in coal studies throughout the world.

Fifth—I would like to recount some of the things which have been accomplished, chemically speaking, in connection with Illinois coals in the last twenty-five years.

Take the matter of classification; so early as the year 1907 a system of classification was worked out which not only indicates the correct location or rank of Illinois coals, in their relation to all other types but by means of it a definite index is obtained whereby coals of the State can be identified or located almost by counties, at least by districts, where the various subtypes may be found. This was a direct outgrowth of some of the early studies under the new organization of the Survey, which sought to draw a more exact line of demarcation between the inert or ash constituent and the organic or true combustible material.

From these studies, grew up the use of the term, "Unit Coal," which is the basis of our system of classification.

Again, one of the early studies was directed toward the peculiar and at the time little known phenomenon of oxygen absorption on the part of freshly mined coal. From these studies has grown a real understanding of the causes which promote spontaneous combustion, and following such information has come about a thoroughly practical and widely used system of storage of Illinois coal. This has involved also fairly complete information regarding weathering and deterioration as it occurs under storage conditions.

This matter of oxygen absorption is also a factor of fundamental importance in the carbonization of coals of the Illinois type, and by following along the lines thus indicated, an effective system has been worked out for coking these coals.

In this same connection, other studies for isolating and studying the properties of the bonding or agglutinating constituents have been pursued, studies on the softening temperatures and the effect on that phenomenon of absorbed oxygen, studies on sulphur and methods for measuring its distribution as pyritic or inorganic combinations.

This list might be considerably extended, but enough has been given to show something of the scope and the type of the work undertaken. In general, it might be said that the work has been directed toward an understanding of the constitution of Illinois coal, and the inherent and specific properties of the type material of which the coal is composed.

The question now arises—what are the developments to be immediately ahead, and have these factors of the past twenty-five years furnished any help to the requirements, especially of an everyday and industrial sort, for meeting the immediate needs of the future?

In the first place, it will be well to emphasize the necessity for investigational work.

It is difficult to understand why this need has not been recognized in the past, and it is certainly a crucial question for the future. I am sure we do not adequately estimate the relative value and importance of the coal resources of the State. The annual sale value, at least, to the ultimate consumer, is approximately one-quarter billion dollars. If we credit the agricultural product at 10 dollars per year for every acre of area in the State, the value will be about the same as that given to the annual coal yield. Now, the total sum spent on agricultural investigations up to the present time can be measured only in terms of millions of dollars. By contrast, the total amount spent on *coal investigations* up to the present time amounts to just about thirty cents.

Of course, I am speaking in somewhat figurative but, I believe, relatively accurate terms and, especially would I not wish to be understood as criticizing the expenditure for agricultural research. The results in that field amply justify the expenditure, and difficult as are the agricultural problems today, it is sufficient answer to criticisms directed toward agricultural invesitgations, to ask what the present-day status of agriculture would be without that help. In fact, the dominant need of the day, in every line of activity, is for *research* to meet the competitive results of other research, and the coal industry is no exception to the rule.

Now the tendency on the part of every industry is to see only its own problems and perplexities, but the unraveling of a problem is not necessarily research. Its solution however may be possible, or of permanent rather than temporary value only if the fundamental factors are at hand for application to its solution. My plea therefore is that the coal industry make this distinction, and have an adequate appreciation of the value and need of that kind of investigational work as shall develop fundamental facts, whether their immediate value can be seen or not. It is all very well to inaugurate a sales-propaganda to "buy more Illinois coal," but that gives only a temporary and evanescent relief. If the industry can see it's ultimate salvation only in a slogan, I have one at hand, ready-made, namely, "Say it with flowers."

No, the need is more fundamental and involved, and requires a view-point for its solution which may be far removed from the pit mouth and the market.

Nor is it strange if these facts do not come into the range of vision of the coal operator. He has enough to occupy his attention in connection with fixed charges and labor costs, with market conditions and balance sheets. He can understand, of course, a straight red line drawn from Kansas City to Chicago, and marked as a proposed pipe line for natural gas but he has no data, or only a vague conception of how that fuel competition may affect or may be met by the coal industry.

It is obvious that about all that can be done at the present time is to state the problem. I have tried to indicate what the character of its solution should be. The sky is not all over-cast, there are a number of bright spots coming into view. I must say, however, that you must look outside of Illinois to see them; such gleams of hope, for example, as come from the U. S. Bureaus of Mines, the Battelle Institute for Metallurgical and Fuel Research, the International Conferences on Bituminous Coal held at Pittsburgh, and we must also mention the numerous bureaus supported partly by public funds and partly by the coal interests, in England, Germany and France.

Users do not all require their fuel in the gaseous form nor all in the solid form, but all are more or less insistent that it shall be in better form, with less of dirt and grime, with more freedom from smoke and ash and sulphur, and with more care and attention. The old-time operator may have said, "I am mining coal for the one purpose of selling coal." But the future operator will be obliged to say, "I am mining fuel, and I find that fuel must be supplied to the public in the form which they require, regardless of my own wishes in the matter."

But, whatever the form, it is my conviction that the Illinois coal operator has it, potentially, in better form, or by subsidiary operations, can have it, and that his ultimate goal should be and doubtless will be, the mining out of the ground of more nearly 100 per cent of the precious fuel deposit there entrusted to his development, and bringing it to the ultimate user in some form which will always grade as No. 1, and that with the absolutely ultimate essential of a profit.

RECENTLY DEVELOPED METHODS OF RESEARCH IN THE CONSTITUTION OF COAL AND THEIR APPLICATION TO ILLINOIS COALS[1]

By Reinhardt Thiessen[2]

INTRODUCTION

During the last few decades, considerable advance has been made in the study of the origin, constitution, and structure of coal, so that these phases of research are well known. We are now entering on a new phase of research in which, besides endeavoring to pry into the chemistry of coal, the structure and constitution of coal are being correlated with its behavior under different uses.

The United States Bureau of Mines[3] is undertaking a chemical and physical survey of American coals so as to collect data concerning the behavior and suitability of coals under various conditions and uses. There is a considerable number of types of coal, each of which may be suitable for a special purpose or a better purpose than for that now used. The selection of these types of coal for the purposes for which they are best suited requires a knowledge of their composition and physical and chemical natures. A more complete knowledge depends further on the elucidation of the constituents or ingredients of which coals are composed, and the relative proportions in which they build up a coal.

COMPOSITION OF COAL

To make this clear, a brief review of the structure of coal, as it is now known, is necessary.[4] Coals are composed essentially of two visibly different classes of constituents, anthraxylon and attritus (Fig. 16).

[1] Published by permission of the Director, U. S. Bureau of Mines. (Not subject to copyright.)

[2] Research chemist and microscopist, Pittsburgh Experiment Station.

[3] Fieldner, A. C., Davis, J. D., Reynolds, D. A., Determination of Gas-, Coke-, and By-Product Making Properties of American Coals. Read at Atlanta, Georgia, meeting of the Amer. Chem. Soc., April, 1930.

[4] Thiessen, R., Compilation and Composition of Bituminous Coals. Jour. Geol., vol. 28, pp. 185-209, 1920.

Thiessen, R., Structure in Paleozoic Bituminous Coals. U. S. Bureau of Mines Bull. 117, p. 296, 1920.

Thiessen, R., Origin of Boghead Coals. U. S. Geological Survey, Professional Paper 132-I, pp. 121-138, 1925. In shorter contributions to General Geology, 1923-1924.

Thiessen, R., The Microstructure of Coal. Jour. Roy. Soc. Arts, London, vol. 74, pp. 535-557, 1926.

Thiessen, R., and Francis, W., Terminology in Coal Research. U. S. Bureau of Mines Tech. Paper 449, 1929; Fuel, vol. 8, pp. 385-405, 1929.

Anthraxylon

Anthraxylon comprises those constituents in coal derived from the woody tissues of plants, such as stems, limbs, branches, twigs, roots, including both wood and cortex, changed and broken up in fragments of greatly varying sizes through biological decomposition and weathering during the peat stage, and later flattened and transformed into coal through the coalification processes, but still present as definite unit constituents. With the naked eye they appear as homogeneous black bands, strips, or lenticular inclusions, generally of a bright outward appearance, varying in thickness from a fraction of a millimeter to several centimeters (Fig. 16). In general, they have a smooth black to a highly lustrous appearance according to the rank of coal—the higher the rank the higher the gloss. In thin section under the microscope these bands invariably reveal some of the original plant structure. This may be well preserved, or it may be recognized with difficulty, with all degrees of preservation between these two extremes (Fig. 17).

In the living and sound condition, wood is composed essentially of lignocellulose, which is cellulose and lignin. With these are associated a number of other substances, mostly pentosans in smaller amounts. It has been found that when wood is left in a favorable condition for rotting, the cellulose and pentosans are readily decomposed, but the lignin generally remains and in some way is converted into that substance termed humus or humins. Samples of woody peat are found to have lost most of the original cellulose and pentosans, but they have lost little of the lignin. When such samples are examined with respect to the age of the deposit, in other words, in a profile from top to bottom, it is found that although near the surface, as a whole, a considerable amount of cellulose is still present, it decreases toward the bottom, where there are merely traces or none.[5] From this and other criteria it is deduced that the anthraxylon in all the coals is largely derived from the lignin of the plants. Unfortunately, the chemistry of lignin is not understood.

The woods of recent plants vary greatly in the ease in which they are attacked by micro-organisms, also in the ease in which they are macerated, so that the final products of decomposition and sizes of fragments resulting differ in many respects. For that reason the anthraxylon units in coal vary in similar respects.

It is mainly the anthraxylon that possesses the coking properties, and it chiefly lends these properties to the coal as a whole.

Attritus

The attritus is that component in coal derived from any and all plant matter contributed to the deposit during the peat stage, macerated and com-

[5] Thiessen, R., and Johnson, R. C., An Analysis of a Peat Profile. Ind. and Eng. Chem. Analytical Edition, vol. 1, pp. 216-220, Oct. 15, 1929.

minuted through the agencies of micro-organisms, lower forms of animal life, and meteorological agencies, and subsequently consolidated and changed into coal. The attritus, therefore, contains much of the more and most resistant plant products. It is much duller in appearance than the anthraxylon, being usually of a dull gray color and of a striped appearance when intercalated with fine sheets of anthraxylon (Fig. 16). The attritus is the continuous fundamental matter, the disperse medium, in which the anthraxylon is embedded.

When thin sections are prepared from a coal and examined under the microscope at a low magnification, the attritus appears as a granular grayish mass lodged between the more homogeneous dark red bands of anthraxylon (Fig. 33). At a higher magnification—at 200 diameters and more—it is shown to consist of a number of different ingredients. Figure 18 represents a typical transparent attritus, and the following ingredients may be recognized in it:

1. Humic degradation matter
2. Opaque matter
3. Resinous matter
4. Fats, oils, waxes
5. Charred matter
6. Mineral matter

Besides these,

7. Cuticles are also found in all coals, and
8. Oil algae in some coals.

These ingredients have been studied in peat and traced through all the ranks of coals, so that their history is fairly well known.

HUMIC DEGRADATION MATTER

It is not easy to define what is to be understood by the term "humic degradation matter." When considered as to origin, a number of classes are distinguishable and shown to be derived from the following:

a. Cell walls of woody tissues
b. Cell walls of cortex, pith, bark, cork
c. Leaf-parendyma wood-parenchyma
d. Certain cell contents such as gums, starch, tannins, phlobephenes, opaque matter
e. Mosses, lichens, liverworts

In peat, particularly in the younger stages, these different classes may be distinguished from one another, but in the higher coals this can only be done with great difficulty or not at all, and so it is more convenient to combine them under the one term "humic matter." In well-matured peat, and in coal after it has been oxidized, they are soluble in alkalies forming a dark brown, colloidal solution, appearing black in concentrated solutions.

The humic degradation matter in coal is therefore largely but not altogether derived from the woody tissues of plants, and like the anthraxylon is largely derived from the lignin. The pure humic degradation matter possesses many of the properties of anthraxylon (Fig. 23).

SPORE-EXINES

Spores are the asexual reproductive organs of the lower plants, such as liverworts, mosses, and ferns. The microscopic spherical bodies consist of the inner living or protoplasmic parts surrounded by a thin membrane, the entine, which is enclosed in an outer relatively thick shell or membrane, the exine. This is composed of a number of resistant substances, such as cutin, esters of higher fatty acids, oils, and resins. All of these are very resistant to chemical reagents, oxidation, and micro-organisms. Because of this resistant nature, while the inner parts are decomposed the exines remain unattacked in relatively large numbers and always form an appreciable part of many coals.

Spore-exines are the most conspicuous constituents in coal, readily seen on account of their clear yellow color and transparency. They are merely the shells or outer walls or coverings of spores of the coal-forming plants, such as calamites, lepidodendrons, sigillaria, and sphenophylls. They may be recognized in the photographs as small linear patches. At high magnification their true nature is more clearly shown, and in cross-section they appear, when whole, as collapsed rings, often bearing wings or appendages. In reality, they represent collapsed spheres. Their contents have completely or almost completely disappeared. When seen in horizontal sections where they are shown on the broad side, they appear as circular to oval and sometimes slightly triangular discs. At high magnification they reveal many forms of sculpturings, tetrasporic markings, and hair-like appendages (Fig. 19).

There are many different kinds and sizes of spores in coals, and two kinds are recognized with respect to size—megaspores and microspores. From a biological standpoint these also differ in function.

The thickness of the spore-wall varies greatly with the kind of spore from which it was derived, and ranges from the tiniest film to huge, massive megaspores, easily visible to the naked eye.

Pollen-exines resemble spore-exines in general appearance and chemistry, but they are always relatively small and very thin.

It has been shown that the spores are the oil-yielding constituents in coal, cannel coals, and oil-shales. A coal, a cannel coal, or an oil-shale rich in spores is invariably also rich in oils.

CUTICLES

All leaves, fruits, and green stems of the higher plants are covered with cuticles to protect them from insects, bacteria, fungi, weather, et cetera.

The cuticles are often covered with a layer of wax in the form of a film, of hair-like processes, or of granules. In thin sections they appear as bright, golden-yellow bands, often found in pairs and commonly having serrated borders. The substances forming the cuticles are similar in chemical composition to those of spore-exines, and like them are very resistant to decay and chemical reactions, and for that reason are common objects in coal.

The chemistry of cuticles found in coal has been worked out in the laboratories of the British Safety in Mines Research Board and appears to be similar to that of the spore-exines in coal. On destructive distillation they were shown to yield 11 per cent saturated hydrocarbons, 22 per cent unsaturated hydrocarbons, 22 per cent aromatic hydrocarbons, 22 per cent oxygenated compounds, 11 per cent ether-soluble resin, and 11 per cent chloroform-soluble pitch.

RESINS

A large number of plants, such as the conifers, contain a considerable amount of resinous matter stored up in resin ducts, reservoirs, and fissures found in the wood, bark, and leaves. The chemistry of the resins of living plants is remarkably well known. The amount of these resins varies from a fraction of 1 per cent to as high as 10 per cent of the dry weight of the plant. In the lignites it is easy to find the resinous matter still intact in the anthraxylon and other tissues, exactly where they would be expected to be found. They are also found abundantly in the attritus of the lignites; the wood or other tissues simply decayed while the resins remained behind undecomposed (Fig. 25). The identity of the resins in the lignites is therefore certain. In the bituminous coals, resinous-appearing inclusions are also found in the woody tissues; these, it is safe to assume, are also remains of the resinous substances. In the attritus of the bituminous coals, resinous-appearing globules and particles are also frequently found and sometimes form a considerable part of it (Fig. 20). By analogy it is assumed that they are derived from the natural resins of certain plants.

In thin sections these resinous particles appear as spherical to oval globules of greatly varying sizes and of a dark yellowish-red color.

The products of distillation have as yet not been determined and still offer a field for investigation.

OPAQUE MATTER

The origin of the opaque matter in coal has as yet not been determined. Some indications show that it is derived from cell contents of certain plants. Its chemical behavior is similar to that the humic matter described above, and like it may be dissolved in alkali after oxidation reactions, and so it must be classed with it. When concentrated or predominant in the attritus of a coal, either in certain layers or in the whole bed, it forms the underlying principle of a splint coal (Fig. 27). The opaque matter does not possess good coking properties; in fact, it inhibits coking when present in large amounts.

THE COMPILATION OF COALS

All of the ingredients named except the oil algae are always present in the attritus of ordinary coals. As a rule, the humic degradation matter furnishes the larger proportions, but any one, or occasionally any two may predominate, and thus determine its nature and therefore to a large extent the nature of the coal.

The relative amount and the nature of these ingredients determine the nature of a coal and form the basis of classification into types.

With respect to the presence or absence of anthraxylon, coals may be divided into two great groups, (A) those composed of both anthraxylon and attritus, and (B) those composed entirely or almost entirely of attritus.

A. Coals Composed of Both Anthraxylon and Attritus

Coals which are composed of both anthraxylon and attritus in varying proportions are the banded or striped coals (Figs. 16, 21, 31, and 35). The two components may be found in all proportions, regardless of the nature of the one or the other, and the predominance of the one or the other determines to a large extent the nature of a coal.

(a) A coal may be composed largely of anthraxylous or woody matter, forming anthraxylous coals (Figs. 21 and 22). These are characteristic in nature, very fragile, and have better coking properties than attrital coals of the same rank. There are a number of coals of this type. Coal of the lower bench of the Upper Freeport bed and coals of the No. 6 bed (Figs. 21 and 22) are good examples.

(b) A coal may be composed largely of attrital matter. These also are characteristic coals. The Elkhorn coal is a good example (Figs. 35, 36 and 37). Between these two extremes all inter-grades of proportions of anthraxylon and attritus may be found.

The anthraxylon again may be present largely, (a) as relatively thick and massive units as in Figure 21, (b) all as relatively thin units as in Figure 31, and (c) all possible sizes generally mixed.

The anthraxylon may further vary due to origin, initial decay, and the physical nature, color, and cell contents of the original wood.

THE ATTRITUS

The various ingredients of the attritus itself may be present in varying concentrations in different coals. They may all be present in more or less equal proportions, or any one of them may be entirely or largely absent, but never is one found alone; or any one or two or three may predominate. This is true particularly of the attrital coals. The following types may be distinguished:

(a) *Humic coals.*—The attritus may be composed predominantly of transparent humic degradation matter. There are a number of coals of this type. The Redstone coal is a good example (Fig. 23).

(b) *Spore coals.*—The attritus may contain a large amount of spore matter together with a certain amount of transparent attritus. There are a number of coals of this type. The Pittsburgh coal, and a coal from the Barren Measures, McLeansboro Formation, and certain layers in the Elkhorn coal of Kentucky, are good examples (Fig. 24).

(c) *Resinous coal.*—The attritus may contain a large proportion of resinous matter. Coals of this type are found more often among the younger coals. A coal from Sunnyside, Utah, is an example (Fig. 25).

(d) *Paper coals.*—Cuticular matter may be prominent. A coal from Malowka, Russia, known as *Papierkohle,* is a good example. Certain layers in a number of coals are composed largely of cuticular matter.

(e) *Splint coal.*—The attritus may be composed predominantly of opaque matter. As a rule, a large amount of spore matter is associated with it, but not necessarily so. The anthraxylon in this type generally consists of thin irregular sheets, sometimes but sparingly present (Fig. 26). The attritus of this nature imparts characteristic features to this type, and is called splint coal in America, Mattkohle in Germany, durain in England. Whole beds, or merely certain layers of varying thickness in a bed, may consist of this type (Figs. 26 and 27).

Splint coals are quite different from other coals and are easily distinguishable from them, particularly in thin sections under the microscope (Fig. 27). They are irregular and lumpy, irregular or rough in fracture. grayish black in color, and of a granular consistency (Fig. 26).

LUCID-ATTRITE AND OPAQUE-ATTRITE

The types just characterized belong to the banded or striped coals. It will be seen that they may be separated into two distinct groups with respect to the nature of the attritus. The attritus of the one is distinctly transparent in thin sections, and may be called lucid-attrite; that of the other is quite opaque, rendered only transclucent and partly transparent in very thin sections, and may be called the opaque-attrite.

We have, therefore one type of coal composed of anthraxylon, in varying proportions and of varying thicknesses, associated with transparent attritus or lucid-attrite. These are the ordinary coals often referred to as "humus" coals. The other type is composed of anthraxylon, of varying proportions and of varying thicknesses, but generally smaller proportions and of relative thinness, and associated with an opaque attritus or opaque-attrite. These coals are the splint coals, Mattkohle, and durain.

B. Coals Composed of Attritus

Coals composed entirely or almost entirely of attrital matter, or those in which anthraxylon is entirely or almost absent, are the cannel coals. Three main types of cannel coals are recognized:

(a) Spore cannel coals, in which spores form the chief ingredients (Figs. 28 and 29).

(b) Humic or pseudo-cannel coals, in which humic matter is the chief ingredient.

(c) Boghead coals, in which oil algae form the chief ingredient (Fig. 30).

All of these may be intermixed, forming sub-types.

Fusain

Fusain, mineral charcoal or mother of coal, is found in all coals, generally in relatively small proportions, although occasionally layers are found containing considerable amounts. Its origin and formation is a much debated question upon which there is no agreement.

This constituent is so well known that it requires no description at this time, but it may be pointed out that, although not all, most of the fusain is derived from woody tissue of which the structure is often well preserved. It is higher in carbon and lower in volatile matter than the other components, and has no coking properties.

When present in small proportions it has no marked effect upon the coal with which it is found, but when present in high concentrations, more than 20 per cent, it inhibits coking properties.[6]

TYPES OF COALS

A number of specific types of coal are therefore recognized and are broadly distinguishable, as follows:

1. Banded coals
    - (a) Anthraxyous coals
    - (b) Anthraxylous and attrital coals in more equal proportions
    - (c) Attrital coals
    - (d) Splint coals (opaque-attrital)
    - (e) Humic-coals (lucid-attrital)
    - (f) Spore-coals
    - (g) Humic-spore and spore-humic coals

2. Cannel coals
   (a) Spore-cannel coals
   (b) Pseudo- or humic-cannel coals
   (c) Boghead or algal-cannel coals

Also,
   (d) Spore-humic cannel coals
   (e) Spore-opaque-attrital cannel coals
   (f) Spore-boghead coals

PROPERTIES OF COALS

Theoretically, a coal composed largely of anthraxylous matter should differ in behavior in its uses from an attrital coal; a lucid-attrital coal should differ from an opaque-attrital. A great many of these differences are well known. The characteristics of cannel coals and boghead coals are well known, so are the specific characteristics of a number of banded coals.

Although these types can be distinguished precisely and easily by the microscope, and differences in behavior are being recognized, means have not yet been devised of determining characteristics numerically; we have, therefore, as yet not enough numerical measurements to show specific differences. Engineers and technicians demand figures and curves. A beginning has been made by the U. S. Bureau of Mines in this respect by Fieldner and Davis[7] and their co-workers. A number of coals are being examined with respect to certain physical properties, such as coking, gas- and oil-yielding and composition of these products, as well as the nature of the coke. Complete data of two well-known coals have thus far been obtained—a coal from the Pittsburgh bed from the Ocean No. 2 mine, and from the Elkhorn bed, mine 204, Jenkins, Fletcher County, Kentucky.

The Pittsburgh Coal

The Pittsburgh coal (Figs. 31, 32, 33 and 34) is a mixed anthraxylous attrital coal. The anthraxylon is present as relatively thin sheets in innumerable numbers (Fig. 31). The attritus consists essentially of a humic-spore matter in which the humic matter predominates, with relatively little opaque and resinous matters present. Only occasionally are thin layers met with in which the opaque matter is prominent. The attritus in this coal, therefore, may be called a lucid-attrite. At the bottom of the bed the proportion of anthraxylon is greater than the attritus (Fig. 32). In going topward, the relative amount of anthraxylon decreases and the attritus increases proportionally so that at the top the relation of the two components has been reversed, being predominantly attrital toward the roof (Figs. 33 and 34).

[6] Younkins, J. A., and Davis, J. D., Effect of Fusain and Related Inerts on the Properties of Pittsburgh Coal with Particular Reference to Coking Properties. Work presented for Master's Thesis, Carnegie Institute of Technology, 1929.

The Elkhorn Coal

The Elkhorn coal is distinctly an attrital coal with a relatively small amount of anthraxylon in exceedingly thin sheets, barely enough to make it a banded coal (Figs. 35, 36, and 37).

Distributed along the profile occur a number of typical splint coal bands (Figs. 35 and 36). There are seven in the column examined, varying in thickness from a few millimeters to three centimeters, their total thickness being 17 centimeters, and making approximately 2 per cent of the total thickness of the bed. The attritus is an opaque-spore-humic attritus—that is, humic matter, spore matter, and opaque matter are generally mixed. The opaque matter lends it splint coal characters (Fig. 37), and therefore, although this coal can not be called a typical splint coal, it has definite splinty characters. It is particularly rich in spore matter. No banded coal has as yet been found with as large a proportion of spores as this one.

In these two coals we have now numerical differences with respect to coking and by-products yield. Table 5 gives some of the results obtained by Fieldner and Davis.[8]

Table 5.—*Characteristics of two coals, according to Fieldner and Davis*

	Pittsburgh (Ocean No. 2 mine) (Forked lump)	Elkhorn (mine 204) (Run of mine)
Softening temperature of ash, degrees C.	1399	
Agglutinating power	6700	4300
Agde test fusion temperature, degrees C.	320	340
Agde test, decomposition	390	390
Plastic pressure, mm.	1700 to 2300	440
Total bitumen, per cent	14.4	8.2
Proximate analysis		
Moisture	1.6	2.2
Volatile matter	34.2	36.6
Fixed carbon	56.7	59.0
Ash	7.5	2.2
	100.0	100.0
Ultimate Analysis		
Hydrogen	5.4	6.1
Carbon	77.8	80.9
Nitrogen	1.6	1.5
Oxygen	6.6	8.7
Sulfur	1.1	0.6
Ash	7.5	2.2
	100.0	100.0

A more concise discussion of these coals has been given by Fieldner and Davis.[8] Other coals are under investigation and it is hoped that more data will be obtained soon upon which more definite conclusions may be obtained for a more complete generalization.

---

[7] Fieldner A. C., Davis, J. D., Op. cit.

[8] Fieldner, A. C., Davis, J. D., Reynolds, D. A., Determination of Gas-, Coke-, and By-Product Making Properties of American Coals. Read at Atlanta, Georgia, meeting of the Amer. Chem. Soc., April, 1930.

PETROGRAHPHIC CONSTITUENTS OF COAL ACCORDING TO EUROPEAN INVESTIGATORS

The various constituents in coal when massed in the coal lend a certain appearance to that layer of the coal in which massed. These layers vary in thickness and in some coals may comprise most of the bed or the whole bed.

The Europeans have given these layers or stripes various names according to their appearance, without special reference to their microscopic composition. In England,[9] the following terms are applied; vitrain, bright coal; clarain, striated bright coal; durain, hard or dull coal; fusain, mother of coal or mineral charcoal. In Germany,[10] the following terms are applied for the same types of layers: Glanzkohle or vitrit, bright layers; Mattkohle or durit, dull layers; Faserkohle or fusit, mother of coal. The German investigators find the English term clarain to be superfluous. Recently, Lange [11] sub-classified the Glanzkohle and Mattkohle according to their petrographic appearance as follows:

1. Glanzkohle, mikrostreifig (micro-striped).
2. Glanzkohle, feinstreifig (finely striped).
3. Glanzkohle, grobstreifig (coarsely striped).
4. Feinstreifige, Glanzkohle and Mattkohle in the same proportions.
5. Mattkohle, feinstreifig.
6. Mattkohle, mikrostreifig.
7. Mattkohle, derb (non-striped).
8. Cannel coal.

But neither in England nor in Germany have they examined these petrographic components critically under the microscope, although results of a number of chemical and physical tests are available. There is as yet no unanimity of conception of the various terms used. Particularly confusing are the references to the terms Glanzkohle and Mattkohle. It is not quite clear whether Glanzkohle embraces only those unit constituents in coal derived from the woody parts, anthraxylon, or whether it embraces both anthraxylon and lucid-attrite. So also with respect to the term Mattkohle, it is not quite clear whether it refers to coals containing predominantly opaque-attrite or whether

[9] Stopes, Marie C., On the Four Visible Ingredients in Banded Bituminous Coal. Proc. Roy. Soc., B., vol. 90, 1919, pp. 470-487.

[10] Hoffman, E., Aufbereitungstechnische Trennung der Petrographischen Kohlenbestandteile. Glückauf, vol. 66, pp. 529-540, 1930.

Hoffman, H., Die makroskopischen Gemengteile der Saarkohle. Glückauf, vol. 64, pp. 1237-1243; 1273-1280, 1928.

Kattwinkel, R., Untersuchungen ueber die Verkokbarkeit der Gefügebestandteile von bituminösen Streifenkohlen des Ruhrbezirks. Glückauf, vol. 64, pp. 79-83, 1928.

Lange, Th., Der petrographische Aufbau des Sattelflöze Oberschlesiens. Kohle und Erz, vol. 25, pp. 791-802, 1928.

Rittmeister, W., Eigenschaften und Gefügebestandteile der Ruhrkohlen. Glückauf, vol. 64, pp. 589-594; 624-637, 1928.

Winter, H., Die Streifenkohle, Glückauf, vol. 55, pp. 545-555, 1919.

Winter, H., Mikroskopische und chemische Untersuchungen an Streifenkohlen des Ruhrbezirks. Glückauf, vol. 64, pp. 653-658, May 26, 1928.

[11] Lange, Th., Op. Cit.

it refers to coals embracing both opaque-attrite and the ordinary attritus or lucid-attrite. For this reason a precise comparison can not be made, nor can their results obtained in physical and chemical determinations be applied precisely to all American coals.

Yet in general, British and European coal petrography shows of what constituents a coal is composed and in what proportions they occur beside each other. When it has been shown through chemical and physical investigation how the different components differ in structure and behavior, how they influence and disturb one another in combustion and when it has been found through practice how to use each component profitably, they are mined and separated and each sold for the particular purpose for which it is best suited. in the Ruhr district the separation of the constituents, particularly of the gas and gas-flame coals, has been found to be necessary and constitutes a real problem, as it probably will in all cases where it is attempted.

Recently, 58 coal beds of the Ruhr district in Germany were surveyed and the relative amounts of Glanzkohle, Mattkohle (splint coal), Faserkohle (fusain), and mineral matter in each bed were determined in percentages of the total thickness of the beds.[12] For this purpose a column of each bed was polished [13] and then examined under the microscope and the total amounts of each ingredient were measured, so that it is now known exactly how much of each of these petrographic components is in each of the beds.[14]

By determining the behavior of each of these components in the manufacture of gas and coke and the yield of by-products, and also their burning characteristics under the boiler, the suitability of each for the various uses may be learned. With this knowledge it may be possible thereafter to separate the portions of a bed so that each component may be sold for its appropriate uses.

A similar survey has been carried out in the Lower Silesian coal fields.[15] There, instead of working out the different components in percentages, graphic columns are constructed of a number of profiles of the coal beds on which the different types of coal are graphed in their relative thickness. Thus, a column so constructed shows at a glance the type of coal, how much there is of it, and where it is in the mine.

Because in Europe, particularly in Germany, great stress is laid on the differences in the chemical and physical properties of the three petrographic components—bright coal, Mattkohle, and fusain—considerable work has been done to show their differences. It is impossible to go into these data in detail, which in the last two years have become rather voluminous. A few examples will show the trend and give some idea.

---

[12] Lehman, K., u. Stach, E. Die praktische Bedeutung der Ruhrkohlen petrographie. Glückauf, vol. 66, pp. 289-299, 1930.

[13] Stach, Erich, Der Kohlenreliefschliff ein Neues Hilfsmittel für die angewandte Kohlenpetrographie. Preussischen Geologischen Landesanstalt, 1927.

[14] Lehman, K., u. Stach, E., Op. Cit.

[15] Lange, Th., Op. Cit.

Thermal Decomposition Products of Vitrain and Durain

Holroyd [16] made an attempt to obtain definite information on the difference in the distillation under different temperatures of vitrain and durain in two British coals, one from the Hamstead coal and the other from the Barnsley coal. The Hamstead vitrain and durain give the following anaylses (Table 6):

Table 6.—*Analysis of Hamstead vitrain and durain*

	Vitrain	Durain
	Per cent in pure coal	
Moisture	13.40	6.40
Ash	1.30	6.00
Volatile matter	37.51	35.10
Carbon	78.32	80.92
Hydrogen	5.15	4.71
Nitrogen	1.02	1.08
Sulfur (organic)	1.01	0.97
Oxygen	14.50	12.32
Gaseous distillation products of Hamstead vitrain and durain (c. c. per 100 grams ash-free dry coal)		
Carbon dioxide and sulfur dioxide	462	743
Higher olefines	193	166
Ethylene	122	80
Carbon monoxide	466	280
Hydrogen	230	279
Paraffin hydrocarbons	3517	2688
Total gas	4990	4236
Liquid distillation products of Hamstead vitrain and durain, per cent on ash-free dry coal		
Water	8.20	6.98
Light oils	1.50	1.48
Heavy oils	5.82	7.74
Acidic oils	0.56	0.30
Phenolic oils	1.67	1.06
Basic oils	0.18	0.16
Hydrocarbons	1.75	3.69

The results from the Barnsley coal are similar.

Several Germany investigators [17] have given us considerable information concerning the coking properties of the three or four petrographic compon-

[16] Holroyd, R., and Wheeler, R. V., The Primary Thermal Decomposition of Coal: VI—the Comparative Distillation of Vitrain and Durain and the Behavior of the Morphologically Organized Plant Entities. Fuel, vol. 9, pp. 104-114, 1930.

[17] Hock, H., u. Kühlwein, F. L., Gefügezusammensetzung, Inkoklung und Verkoksbarkeit der Steinkohle. Glückauf, vol. 66, pp. 389-395, 1930.

Hoffman, E., Aufbereitungstechnische Trennung der Petrographischen Kohlenbestandteile, Glückauf, vol. 66, pp. 529-540, 1930.

Hoffman, H., Die makroskopischen Gemengteile der Saarkohle. Glückauf, vol. 64, pp. 1237-1243; 1273-1280, 1928.

Kattwinkel, R., Untersuchungen ueber die Verkokbarkeit der Gefügebestandteile von bituminösen Streifenkohlen des Ruhrbezirks. Glückauf, vol. 64, pp. 79-83, 1928.

Lange, Th., Der petrographische Aufbau des Sattelflöze Oberschlesiens. Kohle und Erz, vol. 25 pp. 791-802, 1928.

Rittmeister, W., Eigenschaften und Gefügebestandteile der Ruhrkohlen. Glückauf, vol. 64, pp. 589-594; 624-637, 1928.

Winter, H., Die Streifenkohle. Glückauf, vol. 55, pp. 545-555, 1919.

Winter, H., Mikroskopische und chemische Untersuchungen an Streifenkohlen des Ruhrbezirks. Glückauf, vol. 64, pp. 653-658, May 26, 1928.

ents. They all agree that there is a great difference in their chemical and physical properties, particularly in their coking properties. The "Glanzkohle," or bright coal, always possesses good coking properties; the Mattkohle possesses no or poor coking properties, and fusain never possesses coking properties. Both, when mixed with a Glanzkohle have a deteriorating effect that makes itself particularly felt when exceeding 20 per cent.

Bright coal is therefore considered the most valuable constituent, as it possesses without a doubt the best coking properties and the largest amount of by-products—gas, ammonia, tar, and benzol.

Mattkohle, or splint coal may be used in coking when mixed in the right proportions with Glanzkohle, although alone and when mixed in too large proportions it yields a poor coke. When the Glanzkohle yields a coke too porous or too friable, a certain mixture of Mattkohle will improve the coke. When too large a proportion is used with Glanzkohle, it yields a poor, brittle coke. Mattkohle alone furnishes a dense, hard, and brittle coke.

Fusain comes in for much discussion. On account of the non-coking properties, its presence can only be deleterious. It does not yield many by-products.

Table 7 gives the relation between the four constituents.

TABLE 7.—*Relation of the coking properties of the four petrographic constituents as shown by the Meurice method, according to Kattwinkel*[18]

Coal mixture, per cent	Glanzkohle (anthraxylon) and Fusain	Clarain and Fusain	Mattkohle (splint) Fusain	Glanzkohle (anthraxylon) Mattkohle (splint)	Clarain Mattkohle	Glanzkohle (anthraxylon) Clarain
a : b	a : b	a : b	a : b	a : b	a : b	a : b
100:0	439	138	8	439	138	439
90:10	408	131	0	447	138	439
80:20	423	139	0	449	32	426
70:30	223	92	0	332	92	386
60:40	196	77	0	281	86	300
50:50	138	63	0	212	75	250
40:60	28	34	0	138	36	210
30:70	15	14	0	74	19	180
20:80	6	0	0	27	17	165
10:90	0	0	0	12	10	147
0:100	0	0	0	8	8	138

The foregoing figures give some idea of the different behavior of the petrographic components, as defined by them. A more minute microscopic examination reveals that in our coals many types of coals may be distinguished and so the problem is really more complicated than shown by the European investigators.

[18] Kattwinkel, R., Untersuchungen ueber die Verkokbarkeit der Gefügebestandteile von bituminösen Streifenkohlen des Ruhrbezirks. Glückauf, vol. 64, pp. 79-83, 1928.

CONCLUSION

Much work is yet required in the examination of coals with respect to the nature of the ingredients, the different types of components involved, the determination of their relative amounts and a correlation with their behavior in the use of coal.

These remarks indicate only one line of research; there are other lines that are promising. The physical or colloidal nature of coal, for example, has hardly been touched.

Fig. 16. Block of coal from the Taggart bed, Roda mine, Price County, Kentucky. This block shows the banding as found in most coals. The black bands represent the anthraxylon, the grayish appearing coal between the anthraxylon bands represents the attritus. (Slightly less than natural size.)

FIG. 17. Thin cross-section of coal showing part of anthraxylon in which the cell structure is poorly preserved, yet distinctly discernible. (X 200.)

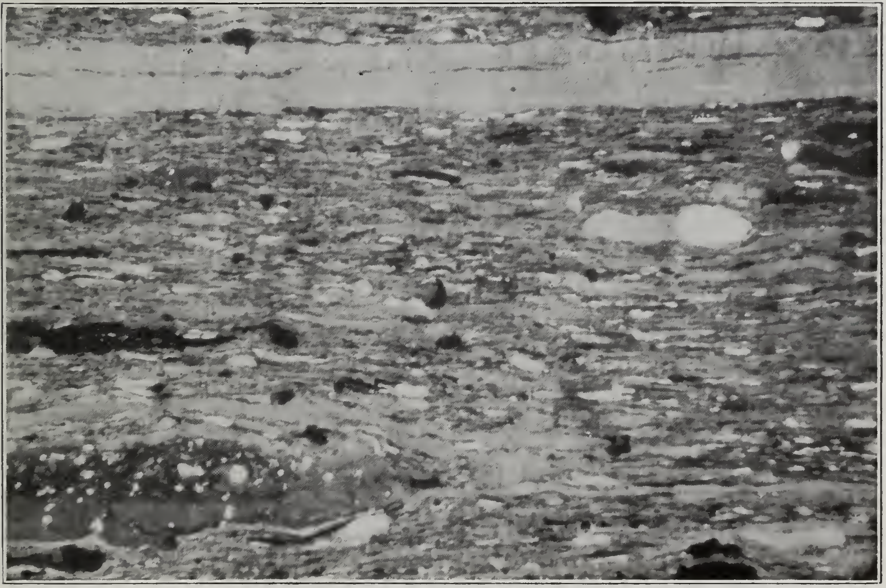


FIG. 18. Thin cross-section of coal from the Upper Freeport bed, showing a transparent attritus. In the upper part is imbedded a thin strip of anthraxylon. The attritus is composed of humic degradation matter, shown in gray; resinous matter, shown as more or less oval particles; spore matter, shown as short thin white patches; opaque matter, shown as irregular black spots; and fusain represented at the lower left corner of the figure. Compare also with Figures 23, 24, 25, 27, 29, 32, 33, 34, and 37. (X 200.)

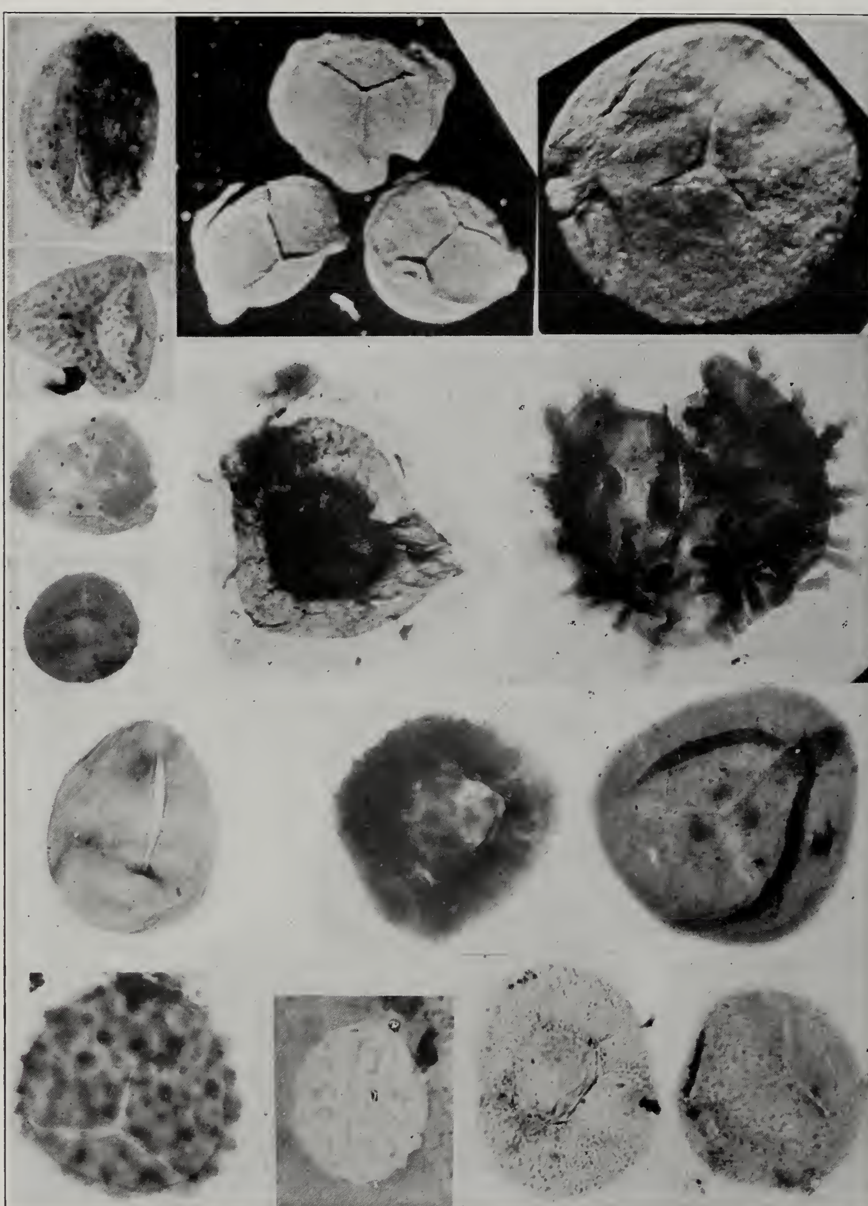


Fig. 19. Spores in coals. Different types of spores isolated from different coals and seen on the broad side.

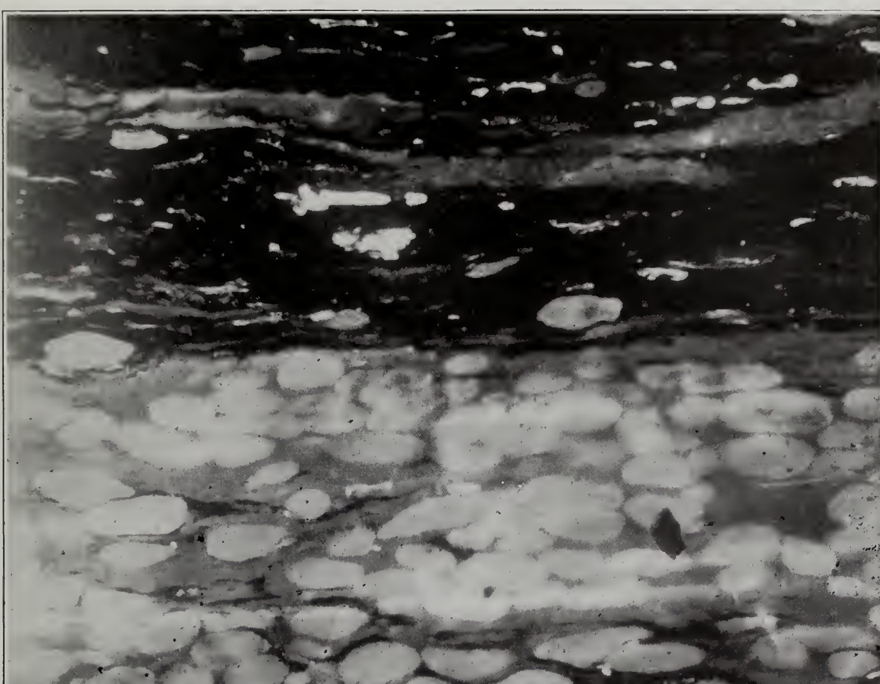


Fig. 20. Thin cross-section of coal from the High Splint bed, Closplint, Kentucky. This shows resin globules either inclosed in solid strands of anthraxylon or separate in the attritus. (X 200.)

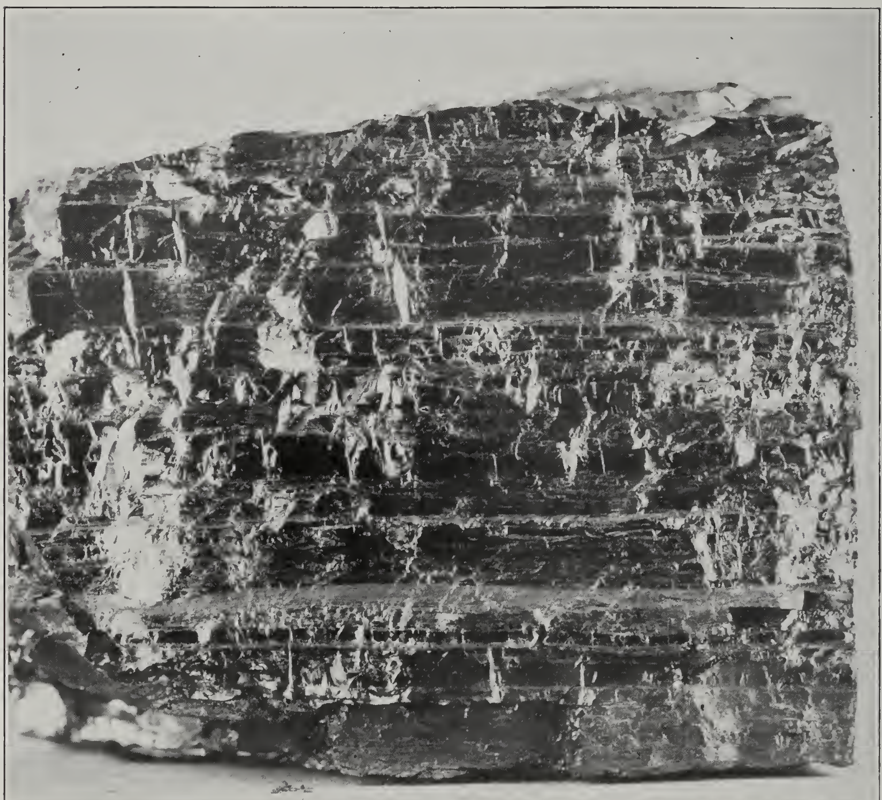


FIG. 21. Lump of coal from No. 6 bed, Old Ben mine, Franklin County, Illinois. This is a block of anthraxylous coal, and appears to be fairly typical of the coal in that mine. Note the broad bands of anthraxylon and compare with thin layers of attritus. See also Figures 16, 26, 31, and 35. (Slightly less than natural size.)

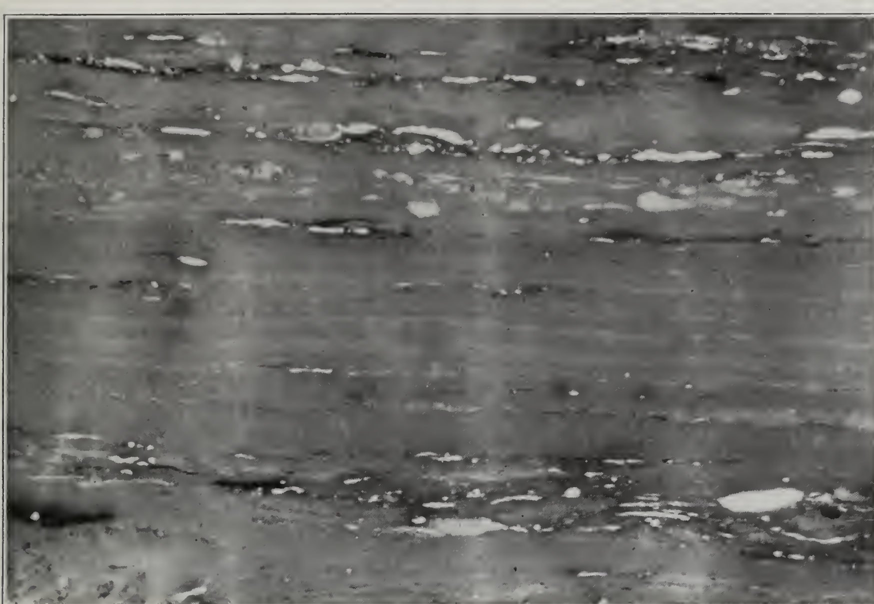


Fig. 22. Thin cross-section of coal from No. 6 bed, Old Ben mine, Franklin County, Illinois, showing the characteristics of an anthraxylous coal. Note the small amount of attrital matter. (X 200.)

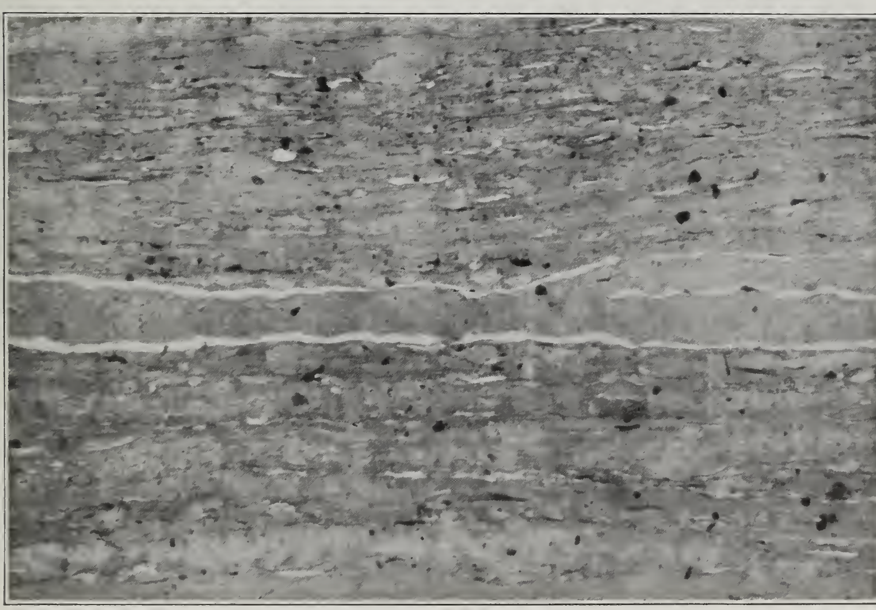


Fig. 23. Thin cross-section of Redstone coal, showing an attritus composed largely of humic matter. Very few spores are present. In the middle of the section is a strip of tissue bounded on either side by a cuticle. (X 200.)

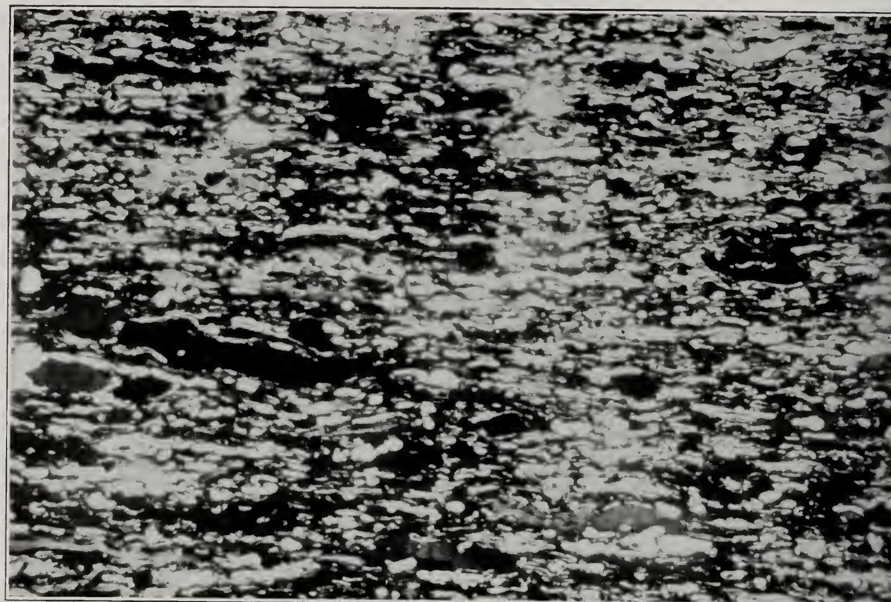


FIG. 24. Thin cross-section of the attritus of a spore coal. Spores, shown in white, form the predominant part; only relatively a small part of humic and opaque matter is present. (X 200.)

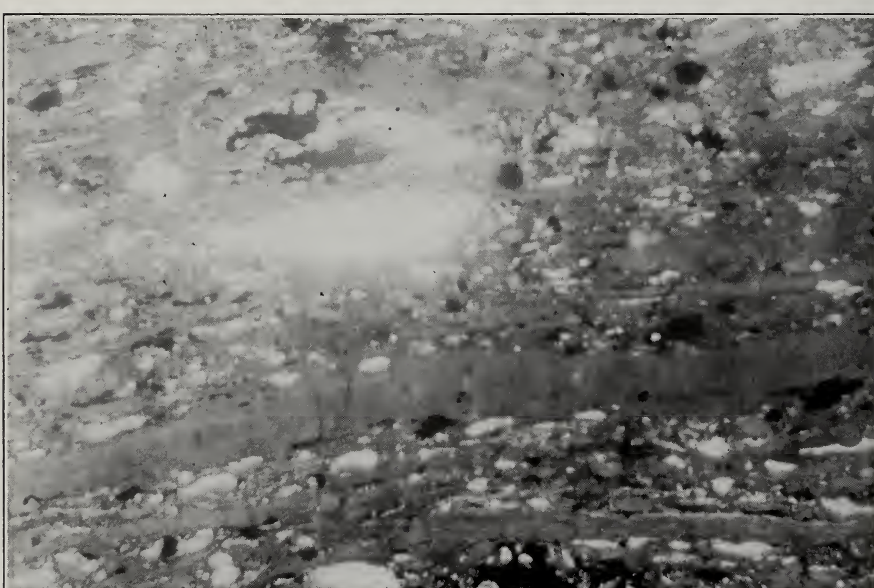


FIG. 25. Thin cross-section of coal from Sunnyside mine, Utah. In addition to the humic matter, the attritus in this coal contains a large proportion of resin in the form of irregular granules of varying sizes and a light yellow color. (X 200.)

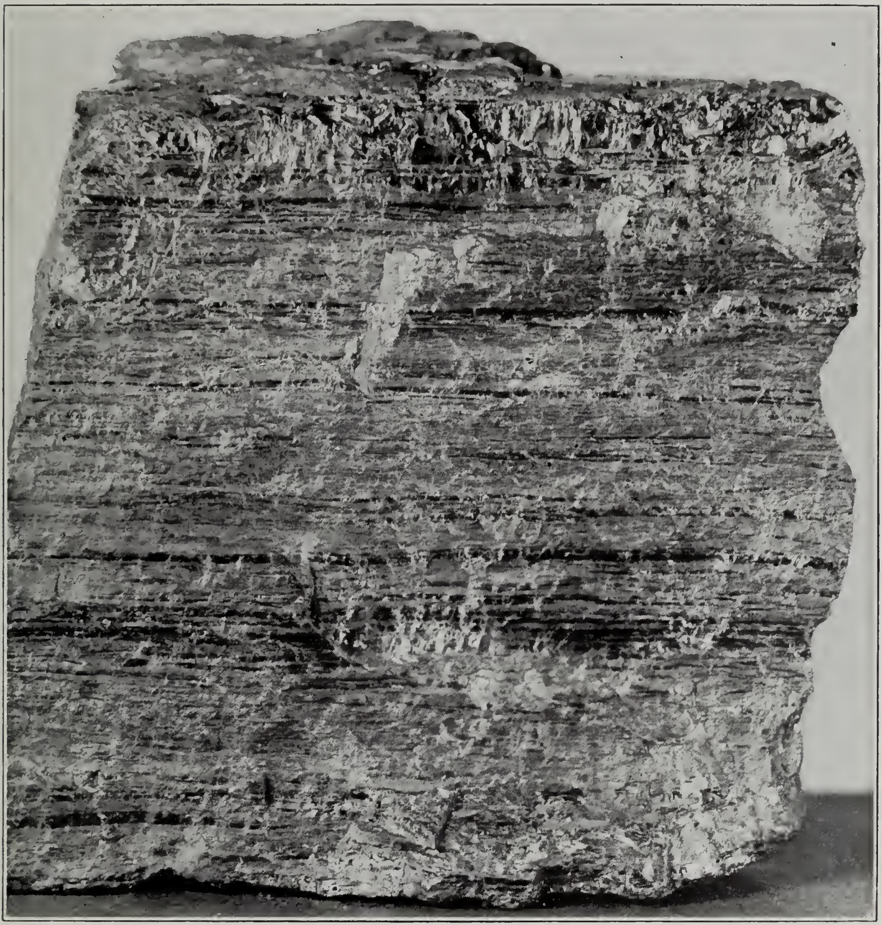


FIG. 26. A block of splint coal from the High Splint bed, Closplint, Harlan County, Kentucky. Characteristics of the splint coals are the large number of relatively thin anthraxylon sheets, and the relatively large amount of attritus. The attritus in this coal is composed largely of opaque matter, spores, and some humic and resin matters. (Slightly less than natural size.)

Fig. 27. Thin cross-section of splint coal from the High Splint bed, Harlan County, Kentucky. The ground mass consists of opaque matter and in a medium thin section is entirely opaque, only the spores, occasional resin particles, and strips of humic matter being transparent. (X 200.)

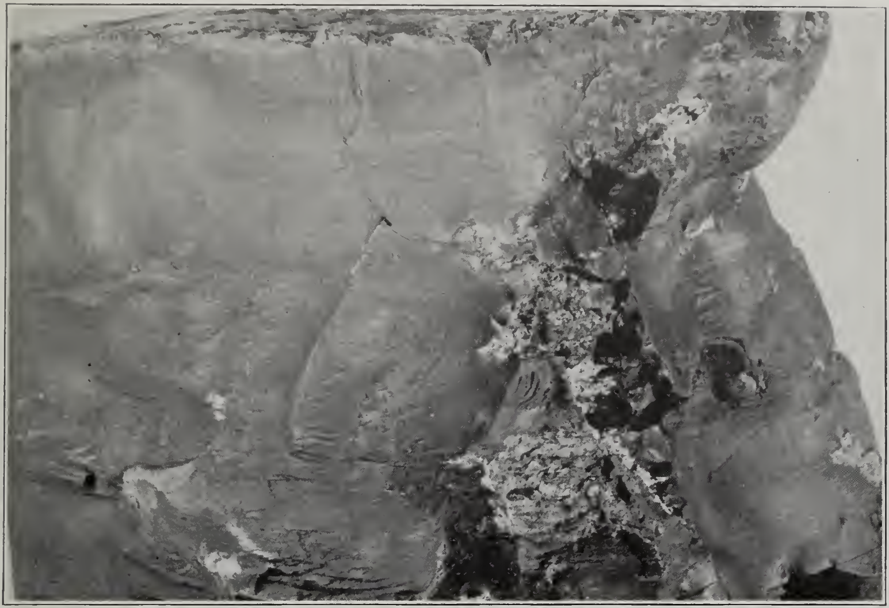


Fig. 28. Block of cannel coal from Cannelton, Beaver County, Pennsylvania. This is a spore cannel coal. See Figure 29. (Natural size.)

Fig. 29. Thin cross-section of cannel coal from Cannelton, Beaver County, Pennsylvania. This cannel coal is composed largely of spores, some humic matter, some resinous matter, and some opaque matter. (X 200.)

FIG. 30. Thin cross-section of boghead coal from Alaska. The white bodies are the so-called yellow bodies, the remains of oil algae. (X 200.)

FIG. 31. Block of Pittsburgh coal. This is compiled of innumerable thin anthraxylous sheets, embedded in equally thin layers of attritus. See also Figures 32 and 33. (Slightly less than natural size.)

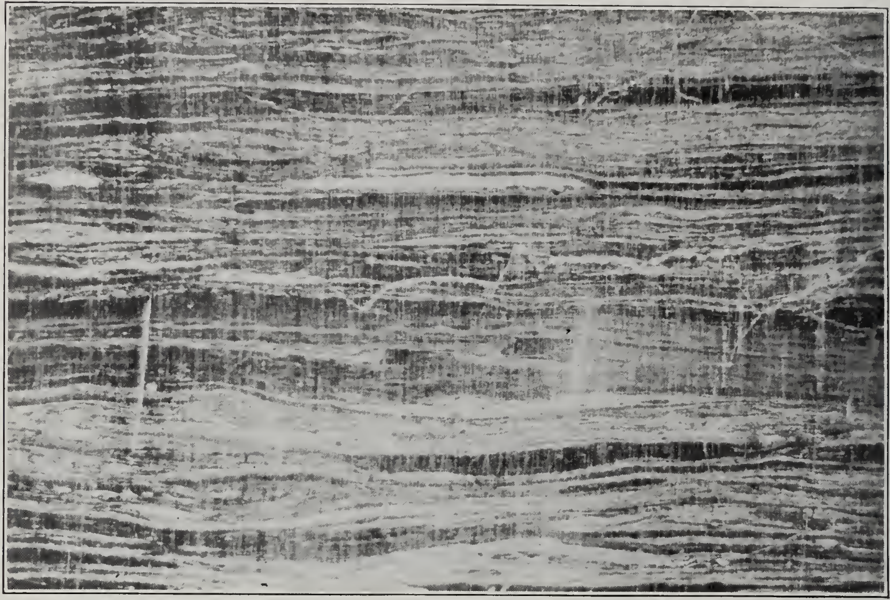


FIG. 32. Polished surface of Pittsburgh coal from the U. S. Bureau of Mines Experimental mine, taken from the lower part of the bed, and containing a larger proportion of anthraxylon than attritus. (X 10.)

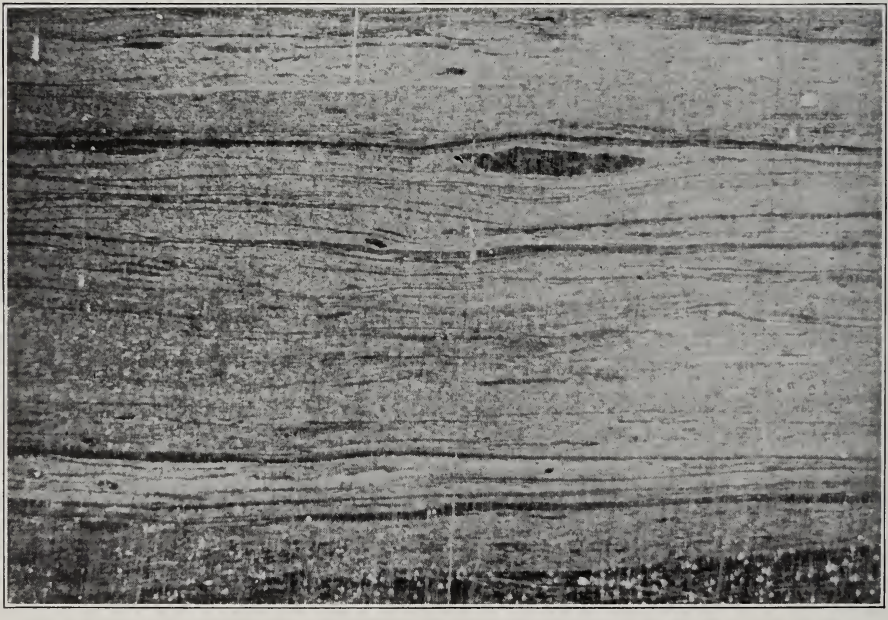


FIG. 33. Polished surface of Pittsburgh coal showing the appearance of the attritus at a low magnification, taken from the upper part of the bed and containing a larger proportion of attritus than anthraxylon. Note that only relatively few thin strips of anthraxylon, shown as black stripes, are embedded in the attritus. Figure 34 shows the attritus of a similar section at a magnification of 200 diameters. (X 10.)

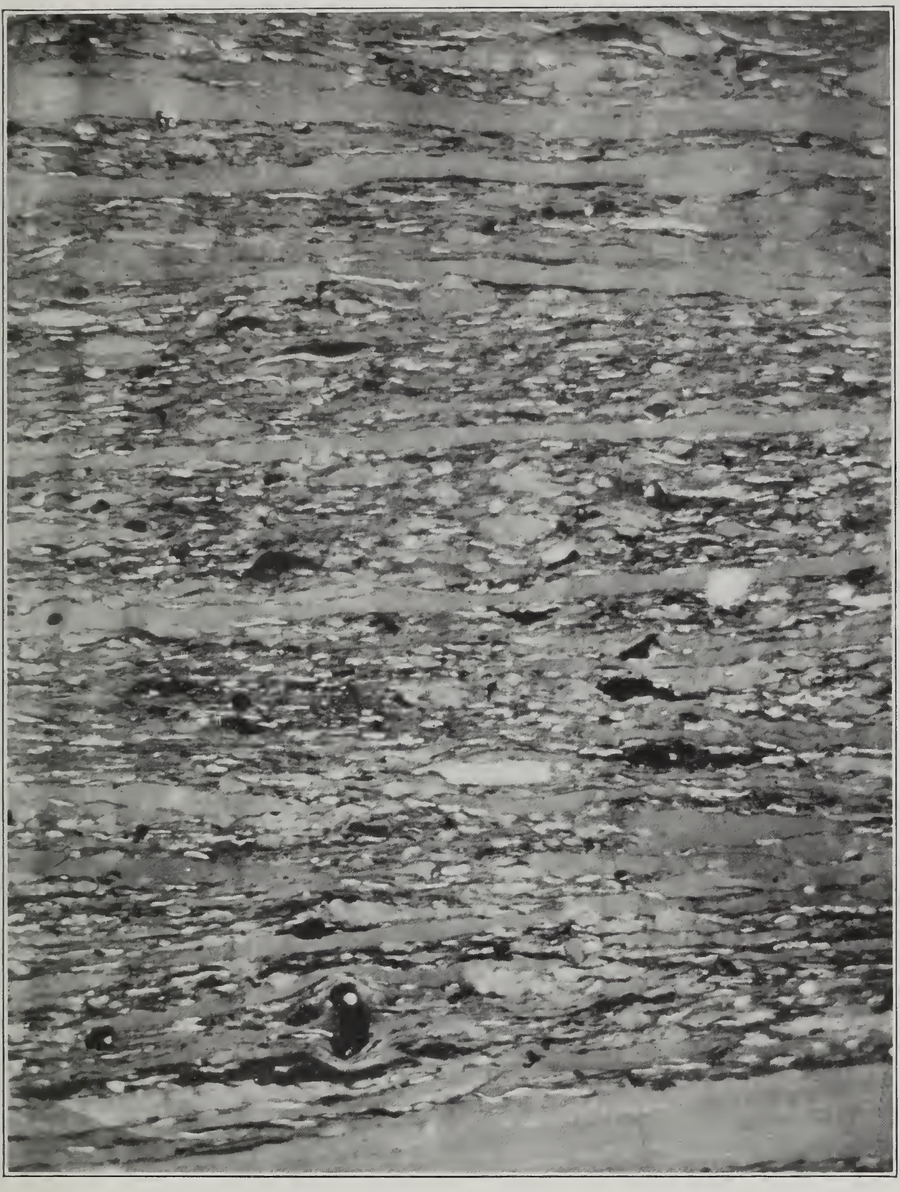


Fig. 34. Thin cross-section of attritus of Pittsburgh coal, taken from a section similar to that shown in Figure 33. This is a typical transparent attritus (lucid-attrite) of the Pittsburgh coal. It is composed essentially of humic matter, spore matter, a small amount of resinous matter and of opaque matter. (X 200.)

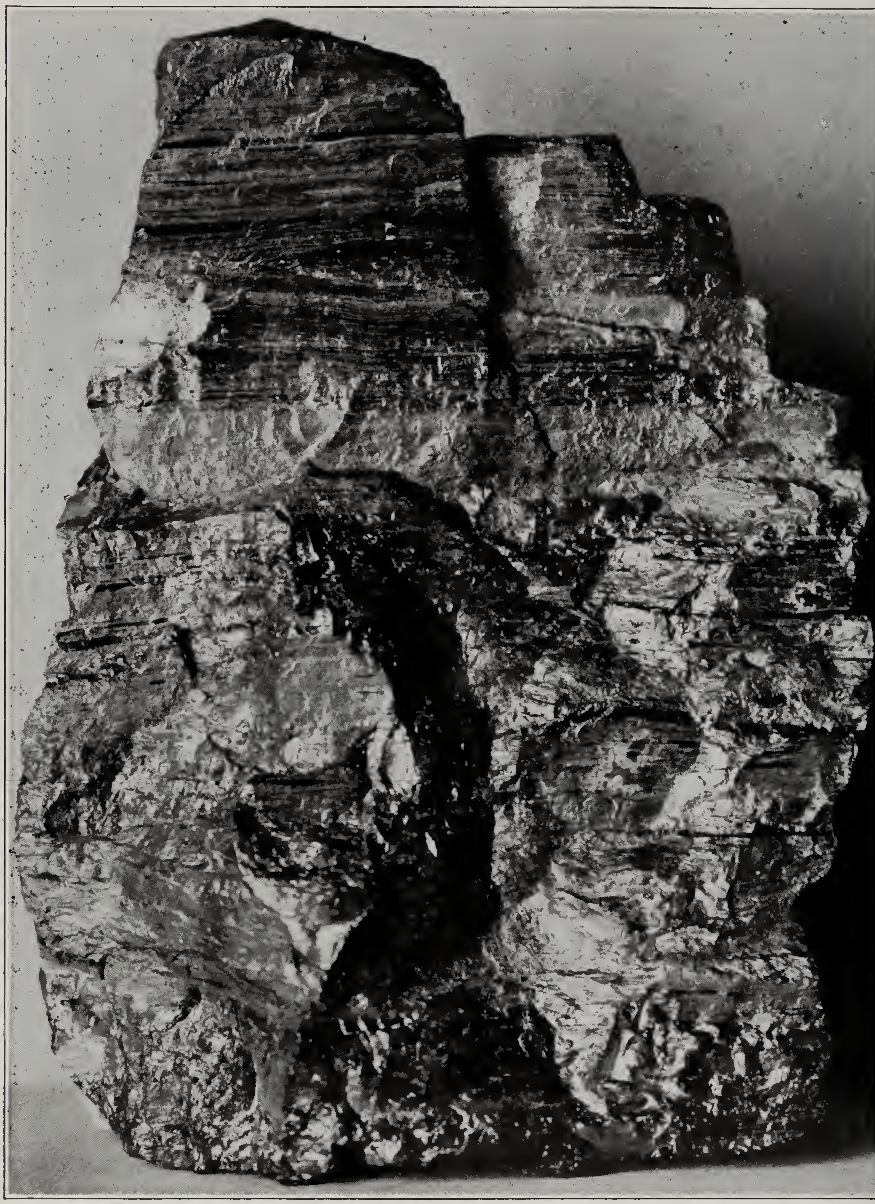


FIG. 35. Block of Elkhorn coal, mine 204, Jenkins, Fletcher County, Kentucky. In the upper part of the block the coal is compiled of a large number of thin strips of anthraxylon and attritus, below this is a band of typical splint coal, approximately 1.5 centimeter thick. The coal below this, forming the larger part of the block, is composed largely of attrital matter, including relatively little anthraxylon in thin sheets. (Slightly less than natural size.)

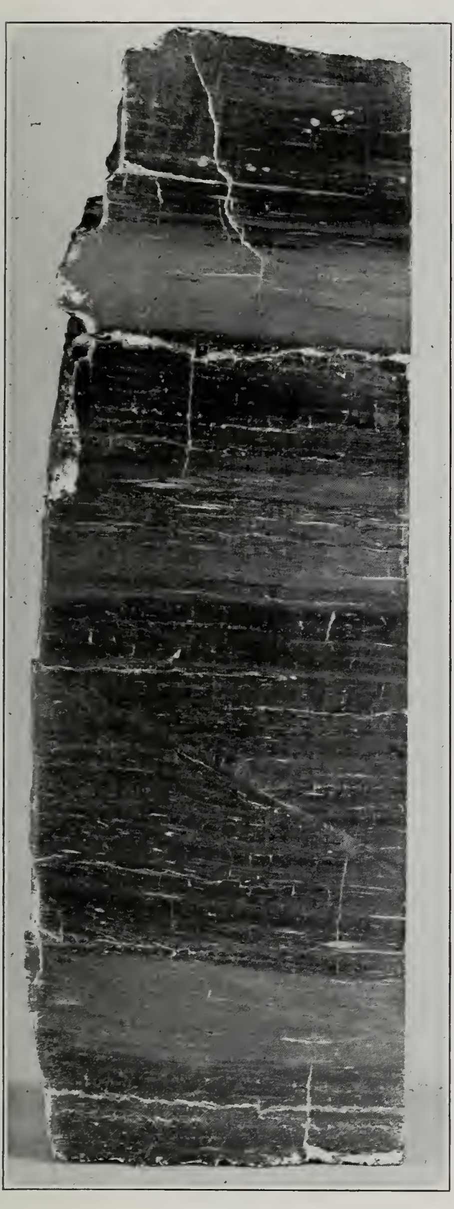


Fig. 36. Polished surface of Elkhorn coal, mine 204, Jenkins, Fletcher County, Kentucky, block from about the middle of the bed. Toward the top and the bottom of the block are bands of typical splint coal. The main part consists of attrital matter, composed of a mixture of humic matter, spore matter, and opaque matter, and relatively little anthraxylon. (Less than natural size.)

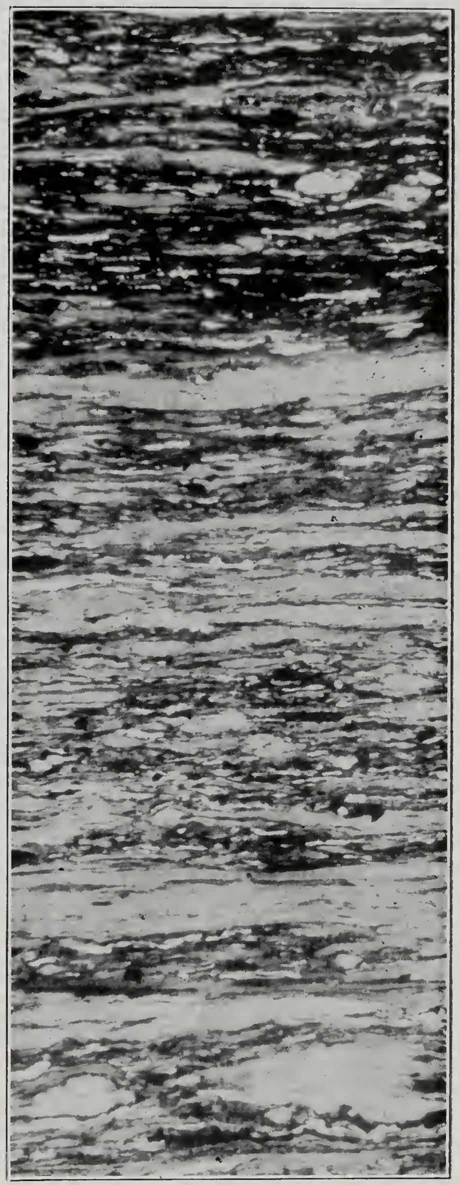


Fig. 37. Thin cross-section of Elkhorn coal, mine 204, Jenkins, Fletcher County, Kentucky. This shows the attritus typical of the Elkhorn coal. It is composed essentially of a mixture of humic matter, opaque matter, spores, and a little resinous matter. The proportions of these ingredients vary some in different horizons. Spores are generally abundant. (X 200.)

Part IV

"Geology and the State"

An Address

By

W. C. Mendenhall
Chief Geologist, United States
Geological Survey, Washington, D. C.

given at the

Quarter Centennial Celebration Banquet

Wednesday evening

April 30th

GEOLOGY AND THE STATE

By W. C. Mendenhall[1]

It is perhaps worth while now and then to pause long enough in our daily activities to make at least a casual survey of our surroundings, remote and near in both time and space, and of our progress, and to do a little conscious thinking about some of the things that ordinarily we take for granted. Such a review may help us to re-orient ourselves; possibly to apply some correctives to our action, and perhaps also we may find some encouragement in contemplating what man has accomplished; some lessons in considering how he has accomplished it, and at the same time we may be helped to realize that a becoming modesty, as we contemplate natural forces and facts, is an attractive human attribute.

We are now using quite casually, and almost without thought, things and forces which in the lifetimes of men now living were merely dream stuff. The telephone, wireless, automobiles, aeroplanes, radium, the whole field of electrical development, the control of infectious diseases; these are a few of the sensational modern developments about which we all know, from which we all benefit, but which we ordinarily accept, without thinking much about what they mean in terms of human progress. We are annihilating distance and time and disease. Men still living can remember when it took 6 months to cross the continent. The Lindberghs crossed it in 15 hours the other day. Where are yellow fever, smallpox, diphtheria? Not much more than bad memories, so far as civilized nations are concerned. Typhoid and tuberculosis are following them into the limbo of almost forgotten things. Among those nations that are able to make use of what is now known, the span of human life is twice or three times what it is among the races that still live as our own ancestors lived not so long ago.

All of this is due to increased understanding of natural forces and natural materials that have always existed, but that have become servants of man, in the modern sense, only during the astounding advances of a scientific age whose dawn we are witnessing.

Science itself has developed with democracy. The release of the human mind from the bondage of ignorance; the spread of education; the recognition of the value and the rights of the individual, are all steps through which the modern state has evolved. This evolution has released the latent intellectual powers of the masses of mankind and enlisted them in the service of further progress. Because self government, political and intellectual free-

---

[1] Chief Geologist, United States Geological Survey, Washington, D. C.

dom, universal education, and scientific progress are interdependent and advance together, all must be fostered if the advance is to continue. Research, the basis of scientific progress, is no less important than the others. Upon it depends man's mastery over nature; the multiplication of his physical powers, and his release from deadening drudgery, and it is perhaps the greatest of modern stimuli to his intellectual development, through its constant revelation of new facts and new relations and its constant calls upon his powers of constructive imagination.

Among modern nations, those that lead in supporting and fostering educational and scientific progress also lead in political and intellectual progress. In such states material prosperity need not be made a matter of direct concern. It is an inevitable by-product of this leadership. It follows scientific and educational progress as surely as day follows night.

Because advancement in the sciences is thus an integral part of modern human progress, the support of scientific activities is one of the criteria by which one recognizes enlightened modern states. We are meeting here during these two days to bear witness to the fact that Illinois meets this test.

Not only because geology is one of the sciences but also because it is one of those upon which each citizen depends daily and hourly, to an extent which he rarely stops to consider, its study should receive state and national support. Geology includes what we know about the earth. That isn't any too much, but it is something, and if in our daily activities we do not utilize what we know and strive constantly to learn more we are unwise; we are not following the path along which progress lies.

Man's relations to geology are peculiarly intimate. This earth is our dwelling place, for the present at least. We live on its surface, at the bottom of a thin film of gas, the atmosphere, which surrounds it. We have been able to go up only some 8 miles into this film which may be 100 or 200 miles thick, and we have not yet been able to penetrate more than a couple of miles into the crust beneath our feet. We may say therefore that our direct personal acquaintance with our planet is limited roughly to a zone some 10 miles deep, around the periphery of a globe 8,000 miles in diameter. That is, all of our activities and all of those of our ancestors have been confined to a zone that would be represented by the thickness of a thin sheet of paper on a globe 10 feet in diameter. So we are pretty well restricted in our occupancy of space, but we are none the less interested in this little zone that we occupy, and from which we gaze outward and inward and pass judgment on the rest of the universe.

Of course we are also interested in other spots in space that may have some resemblances or some relations to our own. It interests us to know that if the sun were hollow and the earth in its center, the moon could revolve about the earth as it does now, and still be almost as far inside the sun's periphery as it is from the earth. It interests us to know that the light that we receive from the sun at any moment left that star eight minutes before, although light is the swiftest thing that man knows, moving with such rapidity that it can travel completely around the earth seven times in one second. Hence, strictly speaking, we do not know whether the sun is in existence or not at the moment when we see it. It interests us to know that the light which gives our astronomers all the knowledge that they have about some of the island universes comparable perhaps to our own galactic system, left the nearest of these on its way to earth nearly a million years ago, so long ago that the northern part of this continent was then buried under the ice of the first of the great succession of ice advances, which molded the surface of this state and gave you the soils on which your great agricultural industry depends. We are interested in other astounding facts told us by the astronomers. Our little earth seems quite adequate to us, yet the sun, just an ordinary star in our galactic system, is more than 100 times the diameter of the earth. Its diameter approaches 900,000 miles whereas the earth's is about 8,000 miles. But huge as is the sun from our point of view, it is a pigmy compared with some of the giants of the universe. We are told that Betelgeuse, the big red star in the constellation Orion, has a diameter 300 times that of the sun, 30,000 times that of the earth, and that 25,000,000 suns like ours could be packed into the space it occupies. All of these findings of astronomical science interest us greatly and to review them tends to prevent us from exaggerating our own importance in the general scheme of things. The modesty of the human race, like the modesty of the individual, increases with knowledge. A man can not be both wise and egotistical, for wisdom leaves no room for egotism. As a race, we used to think that we were the center of the universe; that all the heavenly bodies revolved about us, for our particular benefit, and shed their heat and light for our use and comfort. We are at least not assertive about this now. However, although this planet may not be much of a heavenly body from the astronomer's point of view, after all it is our own, and we propose to stick to it and make the best of it while we can.

Now, what does making the best of it mean? It means many things, involving all the fields of human activity, of course, but I propose tonight to discuss in very general terms only a few of these that are related to the field of geology. This will involve reminding ourselves of some of the so-taken-for-granted things all about us, that we rarely think consciously of them. Geology, of course, deals with the entire earth, but most of its facts have been acquired by a study of the surface of the earth, because that is directly accessible to us. And this accessible surface or near surface contains much that man uses and depends upon. The rocks of various sorts of which it consists underlie all of the land and all of the oceans and make the fairly stable surface on which we live. The seas pound them to pieces, and the glaciers grind them up, and the rivers cut into them, and heat and cold shatter them, and the air and its gases disintegrate them, and the results of these actions are the soils which we cultivate, and from which we derive most of our food, either directly or indirectly. So our soils are the products of geologic processes.

Primitive man seems to have found caves in rocks and shelters under overhanging ledges. Here he took refuge from storms and from enemies and here he established homes and began the art of interior decorating as indicated by the drawings that he has left on the walls. He soon learned to improve these natural shelters by laying together slabs of loose stone and thus building walls about the entrances or actually closing them. In our own southwest, having learned how to handle these materials, to improve the natural shelters, he emerged into the open, and built houses of loose slabs and clay on the mesas. From these simple beginnings to the brownstone front, the marble or crystal palace, or the skyscraper, all built as by primitive man from things taken from the earth, has been a natural evolution, slow at first, but amazingly swift during the past few centuries as man has organized his knowledge and his art. And so, even so far as his shelters are concerned, man from his primitive beginnings has been making use of geologic materials. We do not know when or how he began the use of fire, and therefore of the fuels. Doubtless at first fire was to him, as to other animals, a mysterious and dreaded enemy. But somewhere and some time he learned that it could be controlled and used, that it was a comfort in winter and properly applied to his foods it improved them. Probably he found it first where it had been started by lightning, or spontaneously. Early in recorded history he worshipped it as it was exhibited at the burning natural gas vents in southeastern Europe and northwestern Asia.

Of course, at first he used the obvious fuel—wood. But some early tribesman found, doubtless to his astonishment, that certain kinds of black rock would burn, perhaps he first found it burning in a cliff or a river bank, for coal is often fired naturally and burns indefinitely. Thousands of square miles of our own western prairies are underlain by clinker, left by the burning of the outcropping coal long before the occupancy of the country by white men and doubtless long before the red man's ancestors crossed Behring Straits or the Pacific to this continent.

This black rock is now perhaps the principal fuel that we use. At any rate, we know that man has mined it and burned it for more than three thousand years. We also know that oil from seepages has been used for medicinal and other purposes at least twice that long, although of course the beginning of its development as a great modern source of heat and power goes back only some 70 years to the discovery of the Drake well in eastern

Pennsylvania. Man's three primitive needs, therefore, food, shelter, and fuel, all are related definitely, although in different degrees, to geology. From these basic needs we could expand into a great category of mineral substances—substances with which geology deals—without which modern civilized life in the form in which we know it is unthinkable. Imagine a world without steel, copper, aluminum, coal, oil, and concrete, all minerals or mineral derivatives; it would be a world without railroads, automobiles, airplanes, telephones, telegraphs, electric power and light—in short, without modern communication, transportation or industry.

All of this is just to remind us of what, unless our attention is specifically directed to it, we are quite likely to forget, namely, how dependent we are in all the matters of daily existence upon substances derived from the crust of the earth.

We can gain some idea of the importance of these substances to industry by a glance at the value of the mineral products extracted from the earth's crust. In Illinois, for example, these values have ranged from 180 to 280 millions of dollars per annum during the last half dozen years. This is nearly half the value of your agricultural products, given by the U. S. Department of Agriculture as nearly 450 millions of dollars in 1924.

In the whole United States during the same year the value of the mineral production amounted to about 5⅓ billion dollars and of agricultural crops to nearly 17½ billion. So the crop of mineral substances harvested each year amounts in value to somewhere from ⅓ to ½ that of the agricultural crops.

I think we must all agree that an industry of this magnitude, so basic to all of our daily affairs, is worthy of some organized attention, that is, some attention from the State which is itself an organization of the people created to do those things for the common welfare which fall outside the field of the individual's activities.

A State with a well organized Geological Survey that constantly keeps abreast of developments in the field of the mineral resources, such as coal, oil and gas, building and construction materials, ores and water supplies and prepares for the use of its citizens systematic reports on the occurrence and distribution of these materials, has a very wise and effective form of insurance. The mineral substances, I suppose because, in their natural state, they are beneath the surface and out of sight, seem especially subject to deliberate, or accidental misrepresentation. State and National Surveys render a great service by disseminating reliable information through their publications or by correspondence or personal counsel. In Illinois you have at your service more than 60 volumes of State geological reports, most of them written by men recognized everywhere as authorities on the subjects that they discuss. Such of these as deal with the mineral deposits of any part of the State are sources of sound information for those who contemplate development. Roads are to be constructed. Where will we find the right sort of rock? A great bridge is to be built. What sort of foundations are to be expected at this site? We desire to establish a clay industry in a region where favorable industrial conditions exist. Is there a suitable source there? This city needs an enlarged water supply. Can we hope to get large quantities of water of good quality from wells? Is there hope that deeper drilling in this declining oil field will encounter a lower pool? Does limestone suitable for cement manufacture exist in some county where a large construction program is contemplated?

But direct service of this sort to industry, important as it is, is by no means all that is being done. Valuable contributions to scientific knowledge and to basic educational material likewise appear in these volumes. The teaching of natural science has a recognized and established place in all educational curricula. It is realized that man, as a part of his training for life, should have, as a matter of course, a sound understanding of the world of nature about him. The teaching material, whether in text books or in lectures, is derived from the work of investigators in science, and it is a part of the duty of each scientific group to direct a portion of its energies specifically to this end, that is, to do some work for the mere advancement of knowledge and education regardless of whether it has direct business applications or not. And this part of its duty is likewise being performed by the Illinois Survey, in the issue of its educational bulletins.

It is not necessary in an environment like this, before an audience representative of a great State which has already shown the foresight and the wisdom, first to create, and then to support for a quarter of a century, a sound scientific organization like the present Geological Survey, to advocate public support of scientific work. But I believe that it may be appropriate to set forth briefly the case for pure science as distinct from applied science, for we lend our support generally to the applications of science, rather than to scientific research as such.

Each of us is a layman, so far as another man's special field is concerned. As laymen we are not cognizant of activities in other fields until the results attained in those fields come into general use and thus attract general attention. That is, generally speaking, we do not know anything about the research that is going on until it comes to be applied—until it becomes useful. Then of course we join in the general acclaim. We say, "How wonderful—that is the sort of thing that should be supported."

How often do we stop to think that there would be no applied science unless there were first science to apply—unless first some investigator, driven relentlessly by that curiosity which is at the bottom of all discovery, endowed with that tenacity which persists in the face of repeated failure, and with that imagination which can rearrange and reconstruct known facts and principles and see them in a new perspective; unless such men had spent days or years or a lifetime in the search for a new truth or a new principle. That is research and it is to that kind of work that man owes most of the advances that he has made. Some of the studies have been inspired by an immediate and urgent need and their results were applied as soon as attained. Others were inspired by a mere desire to know, and the applications were left to others and to the future.

Faraday, a century ago, discovered that an electric current was induced in a copper wire moved between the poles of a magnet. Faraday did not profit by that discovery, but today cities are lighted, great manufacturing plants are run, and much of the power used in the world, depends upon the principle that he discovered, that of the electric generator.

The Curies, working obscurely in a Paris laboratory, isolated radium from the mineral pitchblende, and a new curative agent and the basis for new concepts of the constitution of matter were released to the world.

Professor Langley worked for years in Washington developing many of the principles now used in heavier than air machines. His first full sized model plunged into the Potomac. The public jeered and dubbed it "Langley's folly." Nine days later the Wrights who, utilizing many of the principles that Langley had developed, and aided and encouraged by him, had been quietly experimenting for years at Dayton, flew 300 yards at Kitty Hawk. Laymen like you and me were still incredulous. Men had been trying to imitate birds since the dawn of history and had always failed. Therefore, they would always fail. In forming our hasty judgments we forgot the advances in the mechanical arts and the advantages of the research method. Flying is a highly practical art today. Who dares predict the limits of its development in another quarter century?

Sound investigative work, even though not directed toward practical ends, often surprises us by yielding most practical results. Several years ago a report was published on the glacial geology of Wisconsin. It was just a scientific report, giving an interesting story of the various great ice sheets that had pushed down over the state from Canada, within the last million years or so. It was accurate work accompanied by good maps, but it was intended only to give an account of an interesting episode in the pre-human history of the state. Yet I am told that the maps in this report have saved to the state several times the entire cost of the study because they indicated accurately the locations of the deposits of sands and gravels left by the glaciers and needed by the State Engineering Department for the construction of roads. This was an outcome not anticipated, and not sought by the author. It was just an incidental economic by-product of sound scientific work.

These examples, which might be multiplied almost indefinitely, are intended merely to illustrate that fundamental work is always thoroughly worth while. And the most valuable type of such work, that which is directed just to increasing human knowledge in the various fields of science, will not be carried on by industry. It must be supported by organized society which receives its chief benefits. Industry can and will carry on specific researches, directed toward definite limited commercial ends, with profit for a restricted group as an ultimate goal. But some form of non-commercial organization is the only agency that can conduct research on the broad ground that new facts discovered, new principles established, are the basic stuff out of which human advancement is builded, content in the certain knowledge that whatever new is discovered, whether fact or principle, will somewhere, some time, benefit humanity.

The more enlightened modern governments, recognizing this principle, are supporting research more and more, and I hope that Illinois will encourage its State Survey, not merely to continue its successful direct service to the State by its applications of geologic science in daily affairs but also to devote some of its energies to those pure researches in geology, whose applications are not foreseen. They may in the end prove the most valuable of all.

There is one particular respect in which the Illinois Survey, under each of its directors and its successive boards of distinguished advisers, has exhibited a wisdom and established a standard that have increased its value to the State and set an example that others of us associated with similar organizations will follow to advantage. While necessarily confining its own specific activities to Illinois, it has always recognized that political boundaries are not the natural boundaries either of geological problems, or of human knowledge and experience. It therefore has always sought cooperation with neighboring states and with the Federal Survey, and common problems have been the object of joint attack. There have been exchanges of personnel and of results of experience, to the great benefit of both Illinois and its neighbors. Work in your own State is sounder because of this practice and that in other states is likewise benefited. While this cooperative attack on scientific problems generally yields intangible values, that is, results not easily measurable in dollars, one form of cooperation that it has carried out has had definitely measurable results.

In all sound geologic work base maps are needed. This fact was recognized when the present Illinois Survey was organized, and it early entered into an agreement with the Federal Survey for the preparation of topographic maps on a cost sharing basis. To date 31,700 square miles, nearly 56 per cent of the State, have been mapped at a total cost of more than $1,195,000, of which the State has paid $588,000, and the Federal Government $607,000. In other words, the directors of your State Survey, by adopting this cooperative plan, have secured for the State nearly $1,200,000 worth of mapping at a cost to the State of less than $590,000. These are very tangible results. And, although the geologists, trained to the use of topographic maps, are primarily responsible for securing them for the State, everybody now wants and uses them; the road builders, the drainage engineers, those who are planning city or other developments, teachers, atlas makers, etc., and one of the perplexing problems of those administering the work is to select the next areas to be mapped, in the face of conflicting requests.

While topographic mapping is the most extensive cooperative work carried out with the Federal Survey, the two organizations have worked together on many other problems, including those of water supply, coal, oil and gas, and others of less economic and more strictly scientific value. One can not commend too highly this spirit of cooperation which has always been displayed by the State organization. From the point of view of business efficiency, getting the most done for the smallest expenditure; from the point of view of quality of results, that is, bringing together on a problem the men best qualified to solve it; from every point of view, it means efficiency.

The Federal Survey desires to see strong State Surveys in existence. The amount of geological work that needs to be done in the United States merely to help solve the recognized problems that are already acute, the problems of finding more of our essential mineral supplies, is more than all of the State Surveys and the Federal Survey together can do. And new problems will constantly arise as development continues and new mineral substances are put to use. Ores and minerals are geologic entities; they have come into existence through geologic processes; determining where they may be is a geologic problem. We shall all have to work together in the solution of those problems as the demands of the industrial life of the nation become more insistent with the passage of time and the increase of population.

The first director of the U. S. Geological Survey, in a communication to the State Geologist of a neighboring state in 1880, said, "the director desires to announce to you that he urges the inauguration and continuance of State Surveys and wishes to cooperate with them to the mutual advantage of both . . ." This was the policy of the Federal Survey 50 years ago and is its policy today. It is a policy whose spirit has been fully met by the three able directors of the Illinois Survey during its 25 years of existence and that spirit has made cooperation what it should be, helpful to both organizations in the service they are trying to render and profitable to you in your dual capacity of citizens of the State and of the nation.

Part V

Studies Relating to the Order and Conditions of Accumulation of the Coal Measures

A geological symposium planned for the purpose of acquiring as broad a basis as possible for future investigations into the geology, mineral resources, and engineering problems of the Coal Measures

Morning Session, May 1st

Mr. F. W. DeWolf, *Presiding*

THE CONCEPTION OF CYCLICAL SEDIMENTATION DURING THE PENNSYLVANIAN PERIOD

By J. Marvin Weller[1]

CYCLICAL FORMATIONS

More than twenty years ago Udden recognized that the Pennsylvanian beds exposed in the Peoria quadrangle of western Illinois could be subdivided into four parts, each of which is composed of a similar series of strata arranged in the same order.[2] More recent investigations have shown not only that this particular succession of beds is normal and widespread throughout western Illinois but that a similar arrangement of strata in comparable subdivisions is also normal and widespread in Pennsylvanian rocks both higher and lower stratigraphically than those exposed in the Peoria quadrangle. The Pennsylvanian system in western Illinois is, therefore, now recognized as being composed of fifteen such subdivisions, as Dr. Wanless will bring out in some detail, and I have recently proposed that each of these subdivisions be considered as a formation of the Pennsylvanian system.[3]

The members in the typical succession of beds in western Illinois are as follows:

9. Shale, containing "ironstone" bands in upper part and thin limestone layers in lower part.
8. Limestone.
7. Calcareous shale.
6. Black "fissile" shale.
5. Coal.
4. Underclay.
3. Fresh-water limestone.
2. Sandy and micaceous shale.
1. Sandstone.

Unconformity.

All of these strata were deposited under shallow water conditions and it is not surprising, therefore, that there is much variation both in lithology and

[1] Paleontologist, Illinois State Geological Survey.

[2] Udden, J. A., Geology and mineral resources of the Peoria quadrangle, Illinois: U. S. Geol. Survey, Bull. 506, p. 47, 1912.

[3] Weller, J. Marvin, Cyclical sedimentation of the Pennsylvanian period and its significance: Journal of Geology, vol. 38, No. 2, pp. 97-135, 1930.

thickness within any single member at various localities or between similar members in the different cyclical formations. Aside from the local absence of certain members there are few exceptions to the typical succession outlined above, that is, there are very few instances of the presence of members other than those mentioned or cases in which these members occur in a different order.

The fifteen recognized cyclical formations are practically continuous along the Pennsylvanian outcrop in that portion of the State which lies west of Illinois River, and a number of them are believed to have been recognized as being continuous east of the Illinois as far south as East St. Louis. The cyclical formations have not yet been completely traced in this latter area and no detailed observations have been undertaken in southern Illinois with a view toward their determination. However, the facts that the workable coals of the southern part of the State are known to be continuous and extensively developed and that their immediately associated beds are similar to those observed in the western part of the State, make it seem probable that cyclical formations are also widely and typically developed in southern Illinois.

The fact that Pennsylvanian strata in western Illinois may be subdivided into a number of formations which show a cyclical repetition of thin constituent members that are continuously developed over a considerable area is undoubtedly of stratigraphic importance and may be logically employed in the perfection of a natural classification of these deposits. Such a classification is equally useful and valuable whether or not the causes which resulted in such a cyclical repetition of beds are understood. However, if an interpretation that will logically explain the important variations which occur can be developed from the evidence available, there may result a conception of Pennsylvanian physiography and sedimentary conditions which will prove of great value in the correlation and interpretation of sections in other regions. It is with this possibility in view that the hypothesis of cyclical Pennsylvanian sedimentation has been developed.

HYPOTHESIS OF CYCLICAL SEDIMENTATION

The generally prevalent idea that Pennsylvanian sedimentation was controlled simply by periodic subsidence of the interior of North America and consisted of the silting up of a shallow sea and the development of a coal swamp along an advancing coast line, terminated by subsidence, a readvance of the epicontinental sea, and a repetition of this process, does not take into account what was transpiring in the area from which the sediments were derived. Any adequate theory for the interpretation of Pennsylvanian sedimentation must take this into account, as a very close relationship undoubtedly exists between an area of erosion and its corresponding basin of sedimentation. It is obvious that a cyclical repetition of strata reflects a corresponding cyclical repetition of conditions. The conditions that are inferred to have existed are dependent upon the important assumption, which is by no means without foundation, that these conditions prevailed contemporaneously throughout an extensive area.

The hypothesis herein outlined is conceded to be imperfect. It does not explain all that is known concerning the Pennsylvanian stratigraphy of western Illinois. It does, however, account for all of the general and widespread features of the section; relationships which remain unexplained are few and local, and it is believed that there are no facts in direct conflict with it. This hypothesis is therefore presented as a working basis upon which it is hoped that something better may be erected, and all geologists who are interested in this field of investigation are solicited to view their problems in its light, to observe and record data which are considered of importance, and to suggest modifications or alternative interpretations which their experience may lead them to consider necessary.

It is believed that by far the greater part of the Pennsylvanian clastic sediments of the interior of North America were derived from two areas of erosion—Appalachia to the east and Llanoria to the south. Although the sediments of the western interior basin were probably derived largely or entirely from Llanoria, those of the Appalachian basin were undoubtedly carried out from Appalachia, and it seems probable that the sediments of the eastern and northern interior basins also came from this latter region. Therefore, the sedimentary record of Illinois is considered to be related to the erosional history of Appalachia.

DIASTROPHISM

It is of course obvious that subsidence must have predominated in the interior of the continent where sedimentation occurred and that uplift must have prevailed in those areas which were subjected to repeated and prolonged erosion. However, there is no reason to suppose that all movements in the interior were downward and all movements in Appalachia and Llanoria upward. It is indeed probable that there were numerous minor, compensating, reactionary movements in both the erosional and depositional provinces. The borders of continental areas are notably much more unstable, diastrophically, than are their interiors and it seems probable that the movements which disturbed the interior of North America during the Pennsylvanian period were largely induced by more important movements of the border area. It might be expected, therefore, that an important uplift of Appalachia resulted in a less important uplift of the interior and that subsidence of the interior was accompanied by a subsidence of Appalachia, rather than that subsidence occurred in the interior at the same time that there was uplift in Appalachia.

There seems to be good evidence that the major structural features of the interior of North America, such as the several basins, the Cincinnati anticline, and the Ozark dome, were in existence before Pennsylvanian time. There is also good evidence that a certain amount of structural accentuation of these features occurred during the Pennsylvanian period. The present inclination of Pennsylvanian strata about the borders of the various coal basins, however, shows that a considerable amount, and probably much the greater part of the warping along these axes occurred after the deposition of the Pennsylvanian system. There seems little likelihood that the Cincinnati anticline or Ozark dome stood with any important relief above the various basin areas or that they formed conspicuous barriers between several areas of sedimentation either at the beginning of or at any subsequent time during the Pennsylvanian period. At the beginning of Pennsylvanian time the interior of the continent was probably almost a peneplain and whatever slight deepening of the basins occurred from time to time during the period was balanced by the deposition of somewhat thicker sediments in these areas so that the general evenness of the surface was preserved. Upon this surface, which was alternately submerged below and elevated above sea level, accumulated the Pennsylvanian deposits which stretched as a continuous blanket over the greater part of the interior of the United States, overspreading not only the areas of the present coal basins but also extending far beyond their present borders. The subsequent isolation of the Pennsylvanian deposits in the present basins was accomplished by erosion in the areas uplifted by post-Paleozoic warping.

The exact nature of the conditions which resulted in the cyclical repetition of the various types of Pennsylvanian sediments is not known, but it appears that they may ultimately be referred to diastrophic movements, climatic changes, or some combination of these. The series of members which makes up each cyclical formation is complex, and it seems unlikely that climatic changes entirely unrelated to any other conditions should result in such a uniform succession as is exhibited by each formation. Still, climatic change related to or resulting from diastrophic movements which altered the topography of North America probably exerted an important influence on sedimentation but the results of climatic change are difficult to evaluate. Under certain circumstances, additional rainfall might accelerate the rate of erosion, or under others, it might result in a more luxuriant vegetable growth which would protect the land surfaces and thus reduce the effectiveness of erosion. Therefore, at the present stage of this investigation it seems advisable to explain the repetition of beds on the basis of a diastrophic cycle.

THE DIASTROPHIC CYCLE

The postulated diastrophic cycle began with regional uplift of North America, which resulted in the retreat of the shallow epicontinental sea. The newly formed land surface was at once attacked by erosive agencies, and rivers heading far to the east and north entrenched themselves in valleys which in some cases were of considerable width and depth.

Uplift continued in Appalachia but the interior of the continent was not raised proportionally. The rivers which had formerly eroded throughout their entire courses, continued active in their headward portions but the grade of their lower courses was insufficient to permit the transportation of all the sediment with which they were supplied, and so aggradation began. The entrenched valleys were first filled with sands and silts and then the sediments were spread out by the shifting streams to form a comparatively thin deposit on a vast alluvial plain extending from the border of Appalachia to the shore of the withdrawn epicontinental sea far to the west.

The uplift of Appalachia was followed by a slighter but compensating subsidence. This subsidence resulted in a decreased gradient on the alluvial plain. Erosion gradually slackened, finer sediments were carried out upon the alluvial plain and finally sedimentation almost entirely ceased. Shallow irregular basins were formed locally, and in them accumulated calcareous sediments which are now preserved as fresh-water limestones. Some local transference of surface materials occurred, and the shallow local depressions were partially filled by the inwash of small amounts of sediments from slightly higher areas nearby.

A long period of stability then ensued, and upon the recently deposited clastic materials the continued activity of leaching and oxidizing solutions developed a typical poorly drained profile of weathering, in general comparable with those developed on the earlier Pleistocene drift-sheets of the Mississippi Valley.

Additional slight subsidence resulted in still poorer drainage on the great interior alluvial plain. Vegetation, which undoubtedly had obtained a foothold throughout this area as soon as the sea withdrew, became more luxuriant and over extensive areas produced a tangled jungle growth which still further served to impede drainage, and widespread swamp conditions prevailed. In these swamps peat accumulated in greater or lesser amounts and was later carbonized to coal.

Further subsidence submerged the alluvial plain beneath a shallow epicontinental sea in which black muds were deposited, later to become the black "fissile" shales. The carbonaceous content of these beds may have been derived from prolific algal growth which produced stagnant conditions generally inhospitable to normal marine life.

With still further subsidence, the sea cleared and calcareous sediments containing the remains of typical marine organisms accumulated.

Throughout the long period of time that had elapsed since sandy sediments had been spread out upon the emergent alluvial plain, Appalachia had been undergoing weathering but very little erosion. By the time that limestone deposition ceased in the interior of the continent a vast amount of decomposed material derived from the crystalline rocks of Appalachia had been prepared for easy and rapid erosion.

A slight uplift of Appalachia produced a rejuvenation of its streams and active erosion began. This uplift, however, did not at once result in a great withdrawal of the epicontinental sea nor does it seem to have been shoaled to any considerable extent. Into the sea were carried Appalachian sediments which consisted largely of the finer materials, and muds and silts were widely distributed to form a series of marine shales. The sands and coarser materials either remained upon the surface of Appalachia or at most were transported no farther than the sea shore.

Further and more vigorous movement of eastern North America greatly upraised Appalachia, causing the withdrawal of the epicontinental sea and a new cycle was initiated. At first erosion was widely prevalent but as Appalachia continued to rise the streams became overloaded as the result of increased activity in their headward portions and the sands which had remained upon the surface of Appalachia or along the seashore were soon being spread far and wide throughout the interior of the continent to form the basal member of a new formation.

The diastrophic movements which are believed to have controlled the sequence of sedimentation in the interior of the continent occurred in a definite order which was repeated for each cycle. The corresponding movements of the various cycles were not entirely uniform, however, either in magnitude or duration nor were they separated by equal intervals of quiet. Thus the alternate transgressions and regressions of the sea were undoubtedly more or less unequal, the advances during some cycles being much more extensive than in others while in the intercyclical stages the sea withdrew farther at certain times than at others. Also the duration of the different types of sedimentation varied from cycle to cycle. As a result of such minor irregularities, as well as others which were effective only in local areas, the several cyclical formations possess distinguishing characters such as the unusually thick or thin development of certain members, or peculiarities in lithology. In many cases such distinguishing characters are of only local importance but in others they are widespread and of great service in correlation.

This outline of events has been prepared with special reference to western Illinois. The Pennsylvanian section of this region shows a nice balance between continental and marine sedimentation, as might be expected to occur midway on the great interior alluvial plain. Such perfect balance probably does not exist to the east in the greater part of the Appalachian basin where continental conditions predominated, nor to the west in the western interior basin where marine sedimentation is much more conspicuous. The eastern and western sections differ from each other so greatly that direct comparison is almost impossible. On account of its intermediate position and character the Illinois section is, therefore, of the utmost strategic importance. It possesses characters in common with both the region to the east and that to the west and on the basis of these characters it may be compared directly with the sections in both areas. Thus, a detailed knowledge of the Illinois section is desirable for widespread correlation or interpretation of Pennsylvanian conditions, and it is fitting that this State should have furnished the basis for the new conceptions of Pennsylvanian sedimentation. Studies in both the areas to the east and west will undoubtedly reveal facts necessitating revision of the views that have been outlined, but any alternative suggestions originating from one area must be found to be consistent with conditions in the other.

EVIDENCE OF THE DIASTROPHIC CYCLE

The series of events which has been outlined differs importantly in some respects from commonly prevalent conceptions of Pennsylvanian history. Those who are conservatively minded will doubtless question certain features of the cyclical hypothesis and to meet objections that may be raised it seems advisable to present a somewhat detailed discussion of several points. These include (1) the great lateral persistence of the various members of the cyclical formations, which leads to the conclusion that cyclical conditions prevailed throughout wide areas, (2) the continental character of the Pennsylvanian sandstones, (3) the nature and significance of the unconformities which occur beneath the sandstones, (4) the origin of underclays, and (5) the reasons for selecting the unconformities as the boundaries between the cyclical formations.

1. Persistence of Formations

It has long been recognized that certain important coal beds and limestones are practically continuous throughout very wide areas, and numerous examples might be mentioned for the Appalachian, Eastern Interior and Western Interior basins. It has been generally believed, however, that the beds intervening between these persistent horizons are discontinuous, lenticular, and subject to rapid variation both laterally and vertically, but much evidence is now accumulating to indicate that such a view is unsound. Most of the earlier geologic investigations in Pennsylvanian strata were concerned chiefly with the delineation of workable coal deposits. Coals of less than workable thickness have seldom received much attention and the strata between the various coals were examined largely for the determination of key horizons which might serve as guides to important coals. It is not surprising, therefore, that the Pennsylvanian system, composed of several types of sediments which recur monotonously with nearly identical characters at numerous horizons, should have offered little appeal to the imagination and that in general the minute details of the succession have seldom been considered either interesting or important.

More recent studies in several states have clearly shown that the Pennsylvanian succession is much more regular than was formerly supposed. In western Illinois, for example, a number of thin coal beds are now known to be remarkably extensive, and thin strata of other types, such as a series of interbedded limestones and shales possessing certain lithologic and faunal peculiarities, have been recognized at numerous widely separated localities. The clastic sediments—sandstones and shales—which make up the greater portion of the Pennsylvanian succession are somewhat more variable in thickness and lithology but nevertheless they occur uniformly at definite positions in the section.

In view of the fact that detailed studies in several states have revealed a remarkable uniformity in the succession of Pennsylvanian strata, it may be logically concluded that such uniformity is of general occurrence and that the conditions which resulted in cyclical repetition of the various types of sediments prevailed contemporaneously and succeeded each other in the same order over wide areas. The fact that such uniformity of succession has not been recognized in other areas is of little significance unless observations of all portions of the section have been made in sufficient detail to clearly show that such uniformity does not exist.

The belief that the strata of the present coal basins were formerly all connected and that the sediments in all of them were largely derived from the same areas of erosion—Appalachia and Llanoria—is substantiated by (1) the structure of the beds about the borders of the basin, showing that very important down-warping of the basins occurred subsequent to their deposition, (2) the very similar character of the clastic sediments in all of the basins, (3) the increase in thickness and coarseness of clastic sediments as these areas of erosion are approached, and (4) the quartz pebble conglomerates which are known in no sediments derived from other areas but which are present in earlier Paleozoic strata that were without question produced by the erosion of Appalachia. If Pennsylvanian sediments in all the basins were formerly continuous and similarly derived, it is probable that the uniform succession of sedimentary conditions in the various basins paralleled each other contemporaneously, for it is much more likely that contemporaneous periods of erosion succeeded each other at intervals throughout the whole extent of Appalachia and Llanoria than that erosion was irregularly active, here at one time and there at another. If this supposition is correct the cyclical formations of the various basins are exactly equivalent to each other and eventually it should be possible to correlate them with the utmost accuracy and detail.

2. Continental Character of Sandstones

The depositional environments which existed throughout the interior of North America during the Pennsylvanian period have been generally misunderstood. Such loose terms as *the Pennsylvanian sea* or *the Pottsville sea* occur widely in geologic literature but when the physiographic history of the Pennsylvanian period is understood such terms are seen to be misleading. The idea that the Pennsylvanian seas and deposition were similar to those of the preceding Paleozoic periods has resulted in the misinterpretation of continental sediments as littoral, and this in turn has given rise to the conceptions that the present boundaries of the Pennsylvanian strata have been eroded back only a short distance from the original limits of their extent and that important overlaps occur about the borders of the present Coal Measures basins.

The occurrence of marine fossils in those members of the cyclical formations which occur above the coal beds stamps them as being unquestionably of marine origin. It is true that fossils are rare in the upper portions of the upper shale members, which in many cases attain important thicknesses, but they have been discovered at a few places and the unbroken sequence and uniform lithology of these members, which not uncommonly are fossiliferous at the base, indicate the persistence of similar sedimentary conditions, although some minor change seems to have resulted in the seas becoming inhospitable to normal marine life.

With very few exceptions, however, there is no evidence of marine origin of those members of the cyclical formations which occur beneath the coal beds. Indeed, the continental character of most Pennsylvanian sandstones and sandy shales appears to be plainly impressed upon them. Their most distinctive features are their cross-bedded and current-rippled structure, their occasional mud cracks and abundant vegetable impressions and fragments, and their poor assortment which not uncommonly gives rise to rapid lateral variation. The conspicuous pebbly strata in certain important sandstones is clear evidence of fairly strong currents, and the wide distribution of the pebbles at certain horizons and in channels eroded in subjacent beds leads to the conclusion that they were transported by streams rather than by littoral currents.

Lenses of more or less impure coal occur in some of the channel sandstone deposits. Although some of these probably were developed from transported vegetable material, others appear to represent small marshes in which peat was formed in place. It is also significant that Stigmarian root markings are rather common in sandstones at some horizons.

Marine fossils very rarely occur in the Pennsylvanian sandstones of the Appalachian and eastern interior basins. Those few arenaceous deposits which do contain them locally should probably be regarded as the shoreward facies of marine deposits which accumulated contemporaneously with the aggradation of the alluvial plain.

3. Unconformities

Unconformable relations are known to exist beneath Pennsylvanian sandstones at many horizons and in all parts of Illinois. Such relations are so common that the generalization naturally follows that nearly all Pennsylvanian sandstones rest unconformably upon the underlying beds. These unconformities are indicated by (1) an actual truncation of the underlying beds so that sandstones are seen in outcrop to rest upon different strata which end abruptly against the base of the sandstones, (2) the sharp contacts which commonly separate sandstones from subjacent strata, transitional sediments being absent, (3) the local presence of basal conglomerates, (4) the conspicuous variation in thickness of the upper shale member of the subjacent formation at closely spaced exposures, a thinning of this member generally being accompanied by a corresponding thickening of the overlying sandstone, and (5) by the complete cutting out of certain widespread members, such as marine limestones and coals.

At some localities transitional beds do occur between sandstones and the underlying marine shales but such beds are commonly only a few feet thick and have never been observed in the channelled areas. Apparently the erosion which produced the unconformities was not effective over the whole surface of the alluvial plain and certain more or less local and irregular areas which may have stood slightly above the surrounding region were not attacked. If this interpretation is correct, these transitional beds were probably deposited during the first stages of the uplift, perhaps before the sea withdrew, and were subsequently largely destroyed by the first activity of erosion. In this case there is probably present above the transitional beds an unrecognized diastem or break in sedimentation, representing the time required for the erosion of the unconformity and the deposition of sandstone in the resulting depressions.

The fact seems undeniable that at many horizons and over considerable areas the sandstones rest without transitional beds upon a surface of marked irregularity and considerable relief. Such a relationship can only have resulted from erosion which occurred after the deposition of the underlying beds and before the sandstone was laid down. In western Illinois two of these surfaces of unconformity possess a local relief of from 80 to 100 feet. In most cases only the upper shale members were eroded but it is not uncommon for the underlying limestones to have been removed. More rarely the unconformable contact dips still farther and a coal bed has been locally eroded and replaced by sandstone, and in one remarkable instance in western Illinois several thin though well developed cyclical formations have been completely cut out over a small area.

Little attention has been directed toward determining the topography of the surfaces of unconformity and at the present time the general features of only one of them has been worked out over any considerable area in Illinois. A study of the topography of this unconformity has demonstrated the existence of a number of long comparatively narrow channels arranged in somewhat dendritic fashion and converging toward and joining a much wider channel extending approximately at right angles to the tributaries (fig. 41). The little that is known concerning the other unconformable surfaces indicates that they are probably similar.

If unconformities of this type were to be discovered in any of the earlier Paleozoic systems they would undoubtedly be considered of great stratigraphic importance as indications of diastrophic movement and would be employed in a subdivision of the section involved. The fact that they have not yet come to be used generally for the subdivision of the Pennsylvanian system seems to show that they have not been adequately observed or else that they have been considered, for some reason, to be of no particular significance. The interpretation which is to be placed upon these unconformities is, therefore, of great importance and if it can be shown that they are related to and record diastrophic movements, their importance in the field of Pennsylvanian stratigraphy must be conceded.

All evidence appears to favor the conclusion that the erosion which resulted in the Pennsylvanian unconformities was accomplished under a continental rather than a marine environment. The presence of long, comparatively narrow, deeply incised channels or valleys which extend in different directions and, in one case at least, combine in a somewhat dendritic fashion strongly suggests the normal work of streams. The pebbles of locally derived conglomerates show that the shales and limestones which were eroded were already lithified nearly if not quite to their present state and their erosion must have required considerably more work than if they had remained unconsolidated sediments. The sandstones which fill the inequalities of the unconformable surface are considered of continental origin and at a few places there is evidence of some weathering of the unconformable surface before the deposition of the sandstone.

Had the unconformities been produced by the submarine scour of tides or other currents the channels might be expected to be broad and shallow, more or less discontinuous in development or varying notably in depth from place to place, and arranged, at least locally, parallel to one another. It seems very unlikely that marine currents would have eroded through a bed of consolidated limestone when the channel could have been much more easily widened by the removal of the overlying shale. Lastly, continental sandstones could not have been deposited in the channels without the region first becoming emergent nor could weathering have effected the surfaces upon which they now rest.

If the unconformities were produced by submarine erosion there seems to be no reason why they should be extensively developed at only a particular stage in the cycle of sedimentation. It is true that evidence of erosional unconformity has been observed at other horizons in the cycle but such unconformities are not abundant and are, so far as known, of local development and small relief. Also in almost all cases they are associated with beds believed to be of continental origin. If such unconformities were developed by submarine erosion, they should be expected to occur at any horizon within the undoubtedly marine portion of each cycle, which is not the case.

The evidence therefore strongly favors the interpretation that these unconformities resulted from erosion of a land surface by streams. The fact that the unconformities cut out beds of unquestionable marine origin shows that uplift must have occurred to raise these beds above sea-level. The fact that uplift certainly occurred along the Ozark border in western Illinois is demonstrated at numerous localities by the presence of coal beds overlying marine limestones with only a thin intervening underclay. Sandstones and shales which normally occupy this interval are missing and probably were never deposited here. This situation has been observed at several horizons and in each case the limestone is an extensive bed which carries a normal marine fauna and is the caprock of a lower coal. Such limestones accumulated in clear and not too shallow seas. Only uplift could have transformed conditions so that peat deposited in a fresh-water marsh should almost immediately succeed characteristically marine limestone.

4. Underclay

It has recently been determined that the Pennsylvanian underclays of western Illinois are commonly divisible into a series of zones as follows:

1. Dark humus-bearing clay, more or less laminated.
2. Light, bleached, very plastic clay.
3. Irregularly iron-stained clay.
4. Calcareous clay, containing impure limestone nodules grading into the unaltered, silty, calcareous shale below.

This succession is typical of the weathering profile developed under conditions of poor drainage and suggests that underclays were produced by long-continued exposure to atmospheric agents. Underclays have long been considered to represent the soil in which the coal plants grew but recent observations tend to cast more and more doubt on this conclusion. It now seems probable that underclays were completely developed before peat accumulation began and consequently are not genetically related to the overlying coal beds.

The evidence favoring the independent origin of underclays and coal seams includes the following facts: (1) there is no relation between the thickness of associated underclays and coals; (2) underclays are extensively developed at certain horizons without overlying coal beds; (3) coal beds are not always underlain by underclays; (4) local unconformities have been observed to separate associated underclays and coals. This conclusion is also substantiated by the difference in conditions which are believed to be necessary for the development of a poorly drained profile of weathering and of a peat deposit. The former required the leaching and oxidizing action of descending ground water whereas the latter required stagnant water and lack of oxidation.

If this interpretation is correct an underclay represents an important interval of quiescence during which the interior of the continent was a land surface subject to weathering but neither receiving appreciable amounts of new sediments nor being noticably eroded.

5. Formation Boundaries

In each cyclical repetition of beds there appear to be two important breaks in the sedimentary succession: (1) the contact between the underclay and the coal, and (2) the unconformity beneath the sandstone. It is considered probable that the underclay was developed by atmospheric weathering during a long period of quiescence. If this is correct, it is conceded that this time of nondeposition greatly exceeded that required for the development of the unconformity, as more than slight effects of weathering have nowhere been recognized along the unconformable contacts. Because it represents the greatest actual break in sedimentation it might be contended that the contact of the underclay and coal should be used for the separation of the cyclical formations.

According to the accepted practice of stratigraphy, however, periods of instability are considered of primary importance for the subdivision of geologic time. There is no evidence of any marked diastrophism having occurred between the times of underclay development and peat accumulation; in fact underclays and coals have long been considered to have required intervals of unusual stability. The time of underclay development should probably be considered, therefore, as an important diastem and, because continental conditions prevailed, it is indicated by a weathered zone, whereas, if this area had been submerged beneath the sea, no evidence of its existence would be preserved.

The unconformities beneath the sandstones are believed to be the result of important diastrophism and therefore constitute a suitable basis for a natural subdivision of the Pennsylvanian system. From the standpoint of continuity of sedimentation they may be less important than the times of underclay development but from the diastrophic standpoint they are unique. It might be advocated that both the unconformities and the contacts between underclays and coals be employed for the purposes of subdivision but any advantage which such practice might achieve would be more than outweighed by the needless two-fold multiplication of already numerous formations and by the grouping of the coal beds, which are of continental origin, with the marine portion of the cycle of sedimentation. It seems most logical therefore to adopt the unconformities as the boundaries between formations, as would be done if such unconformities were present in any of the older Paleozoic systems.

One of the most important results of the study of Pennsylvanian physiography is the conclusion that over large areas each cycle included an advance and retreat of the sea. The stratigraphic importance of this conclusion is at once apparent but it also promises to be of the utmost value in the field of paleontological investigation. Invertebrate fossils have as yet been of little service in the precise correlation of Pennsylvanian strata. Many of the common species were long ranging forms and most of the others were restricted rather definitely to certain habitats as a result of which few species are known to have any particular stratigraphic significance. Paleontological investigations up to this time have been based upon subdivisions of the section which do not take into consideration that there were many different marine invasions, and therefore the faunas of different invasions have been combined in lists still further obscuring the stratigraphic importance that certain forms may possess. If, on the other hand, collections be made and studied with respect to a series of definite marine invasions it will be possible to arrive at approximations of the total faunas of each invasion. Finally, careful comparisons between these faunas will definitely delimit the ranges of species and varieties and it is to be expected that a number of forms will be discovered to have definite limits which will be of the greatest service in correlation.

CONCLUSION

This outline of the conception of cyclical sedimentation which has been developed with special reference to the western Illinois section and the arguments concerning some of the more important features has been presented in introduction to the symposium of Pennsylvanian sedimentary conditions in order that attention may be directed particularly to those portions of the following papers which deal with matters at present considered to be of special significance.

In conclusion I wish to point out that the subjects which have been discussed naturally fall into two categories. These are, first, matters of fact dependent upon direct observation and concerning which there should be no disagreement, such as the cyclical repetition of strata, the persistence of various strata throughout wide areas, and the existence of unconformities beneath sandstones. Second, there are matters of interpretation concerning which there may be differences of opinion at present but as these interpretations are based upon observed facts and natural laws it is to be expected that when the evidence has been carefully collected and weighed the differences of opinion will largely melt away. Such matters include the significance of the unconformities, the continental character of the sandstones, the origin of underclays, the former extent and source of the Pennsylvanian sediments, and the most logical horizons at which to separate the cyclical formations.

PENNSYLVANIAN CYCLES IN WESTERN ILLINOIS

By H. R. Wanless[1]

INTRODUCTION

Beginning in 1906, detailed areal mapping has been carried on in 18 quadrangles in western Illinois by some 14 different geologists (Fig. 38).

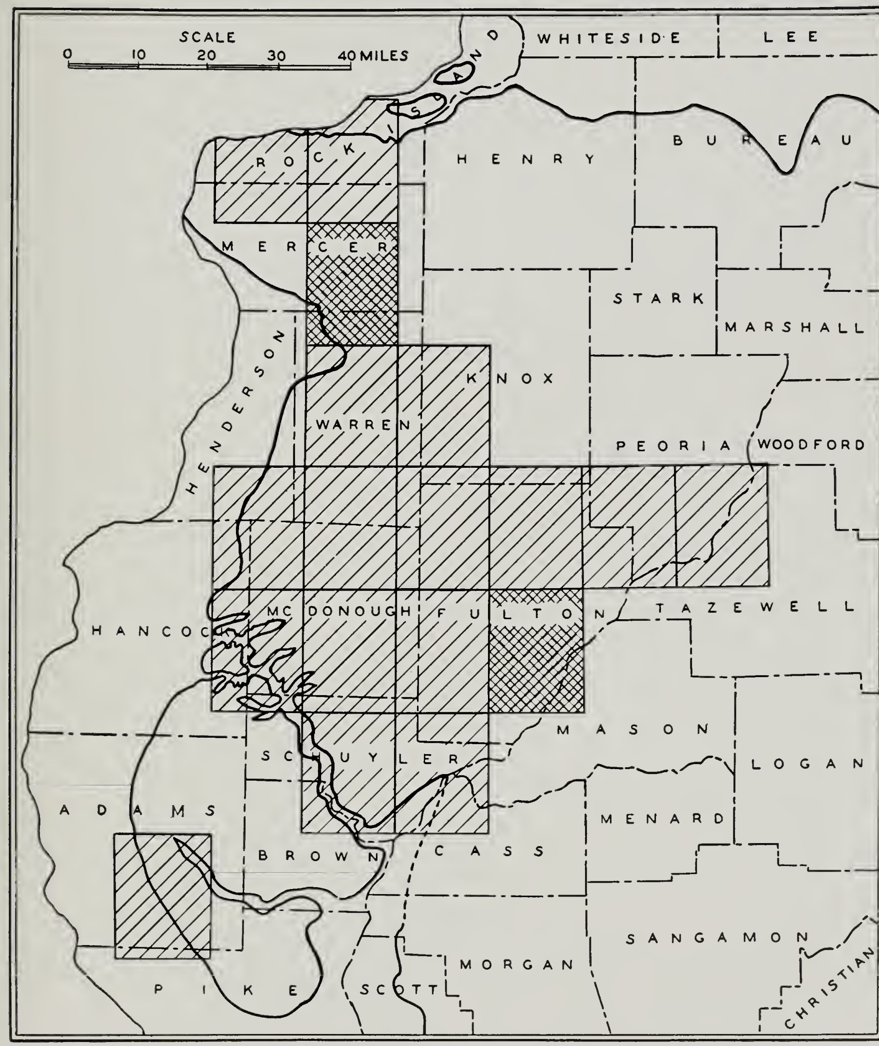


Fig. 38. Index map of western Illinois showing the quadrangles which have been mapped geologically. The Alexis and Havana quadrangles, in the northwest and southeast respectively, are shown by heavier shading. The heavy line bounds the coal basin.

[1] Associate Professor in Geology, University of Illinois, and Associate Geologist, Illinois State Geological Survey.

The writer has mapped two of these quadrangles geologically—the Alexis, situated in the northwest part of this area, and the Havana, in the southeast part, along Illinois River.

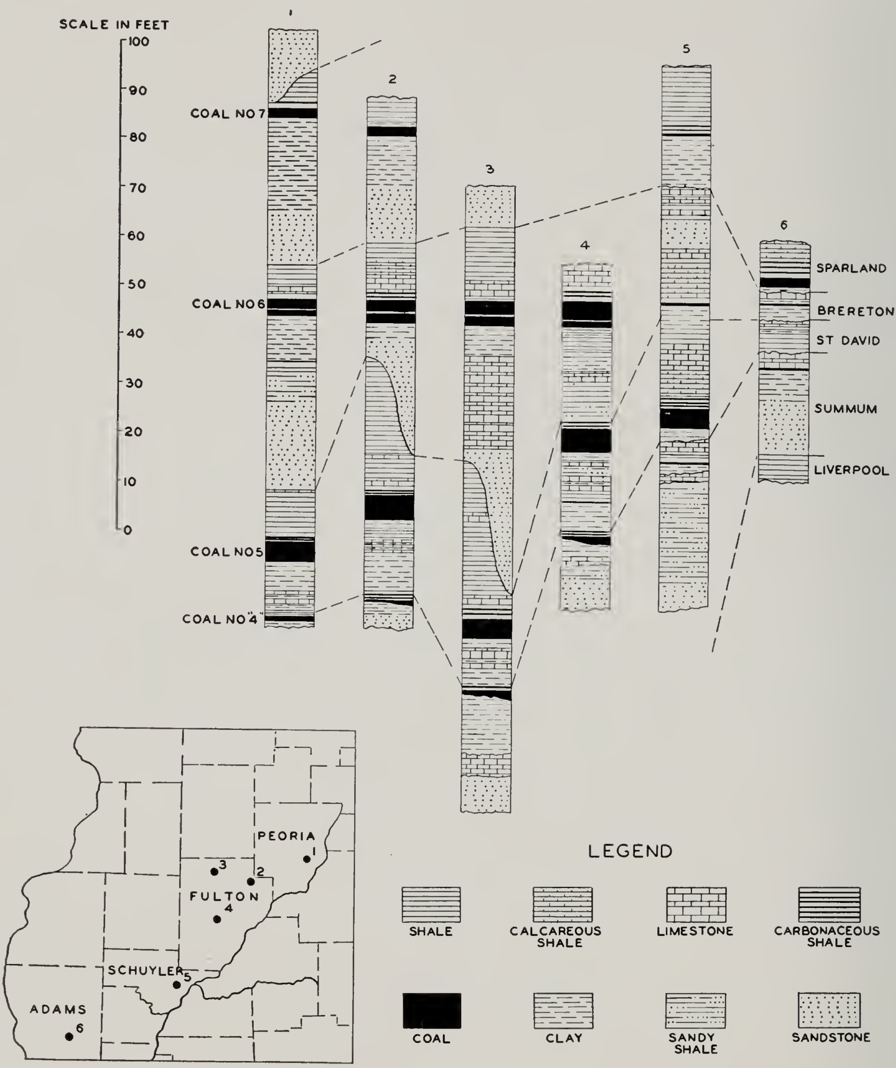


Fig. 39. Geologic sections showing the lower McLeansboro and upper Carbondale strata between Peoria and Liberty, Adams County. Note the thinning and disappearance of coals Nos. 5 and 6 and their associated strata toward the southwest.

During this assignment, the writer became impressed with the similarity of various horizons of the Pennsylvanian system in these two quadrangles, which are about 50 miles apart. The field season of 1929 was devoted to a review of an area of about 4500 square miles which includes most of the mapped area, tracing the various geologic members and noting their persistence and change in character from place to place.

The Pennsylvanian system west of Illinois River attains a maximum thickness of about 500 feet, including Pottsville beds below, ranging from 5 to about 150 feet; Carbondale beds in the middle, with thicknesses ranging from 65 to 160 feet; and McLeansboro beds above, reaching a maximum of about 180 feet.

PENNSYLVANIAN STRATA ABOUT PEORIA

In the Peoria quadrangle, the first mapped in this region, Udden recognized 21 Pennsylvanian strata which could be traced throughout the quadrangle, most of them being remarkably uniform in thickness, and including three coals, each associated with a similar succession of beds (Fig. 39). The beds between coals Nos. 5 and 6 are as follows:

Coal No. 6
Underclay
Shale, sandy, gray
Sandstone, unconformable, locally cutting below Coal No. 5
Shale, gray
Shale, gray, or limestone, shaly, with marine fossils
Shale, black, hard, laminated
Coal No. 5

The succession of beds between coals Nos. 6 and 7 is similar except that the dark shale above the coal is soft and the overlying limestone is persistent. The unconformable sandstone beneath coal No. 7 locally cuts out coal No. 6.

The same succession is again repeated above coal No. 7 except that the limestone is absent. The sandstone again lies unconformably on the lower beds and locally cuts out coal No. 7. This succession is terminated above by a black shale in the Peoria district but by an unnumbered coal elsewhere.

Another similar succession of beds, including an unconformable sandstone, succeeds the black shale and is terminated in the area west of Peoria by coal No. 8. A local unconformity has been noted beneath the limestone of this succession, so that in a restricted area the limestone directly overlies the sandstone beneath.

Above coal No. 8 lies in succession a black shale, a marine limestone, and a gray shale. These are the highest beds recognized west of Illinois River.

REGIONAL PERSISTENCE OF STRATA

The Pennsylvanian strata about Peoria persist and retain most of their distinctive features wherever they occur west of Illinois River. The higher beds persist uniformly throughout the small area west of Peoria where they have escaped erosion and some of them are known at other localities north along Illinois River. Coal No. 6 is divided by a clay parting of nearly constant thickness, the "blue band," in all of its outcrops in three quadrangles west and southwest of Peoria. The lithology of its cap limestone is constant and is distinguished by its abundant specimens of *Fusulina girtyi.*

The unconformity below the sandstone which intervenes between coals Nos. 5 and 6 has been recognized at numerous places outside of the Peoria quadrangle.

The strata associated with coal No. 5 are exposed over a much larger area than are the higher beds. They possess quite similar characters throughout a region including eight quadrangles west of Illinois River.

CYCLICAL REPETITION OF BEDS

As Udden originally pointed out, the strata about Peoria are an excellent example of the cyclical repetition of beds and he grouped them into a number of comparable parts using the bases of the coals as bounding horizons. The breaks indicating the most signficant events in the history of this region, however, are the unconformities beneath sandstones. By employing these the section may be divided into six cyclical formations,[2] thus:

Trivoli cyclical formation containing coal No. 8
Gimlet cyclical formation containing no coal in Peoria district
Sparland cyclical formation containing coal No. 7
Brereton cyclical formation containing coal No. 6
St. David cyclical formation containing coal No. 5
Summum cyclical formation containing coal "No. 4"[3]

The only important irregularity in this part of the Pennsylvanian system is the absence of a sandstone in the St. David cyclical formation. This is of no great significance, however, as several of the other sandstones pinch out and are absent in a considerable area to the southwest.

UNCONFORMITIES

Well marked unconformities exist beneath each of the sandstones. The sandstone of the Brereton cyclical formation almost directly overlies coal No. 5 a short distance west of Peoria and in some places cuts out the coal, but a few miles farther there is 30 to 40 feet of intervening shale. At Cuba, Fiatt, and Fairview the marine fossiliferous beds above coal No. 5 have been cut out. The upper shale member of the Brereton cyclical forma-

[2] These formation names are to be considered tentative. Descriptions of the formations will appear in a forthcoming paper.

[3] This coal is designated "No. 4" for convenience. It is not coal No. 4 of Worthen's generalized section for Fulton County.

tion locally varies from one to eight feet in thickness as the result of the unconformity between it and the overlying sandstone of the Sparland cyclical formation. The sandstone of the Gimlet cyclical formation is locally only one foot above coal No. 7 in the Peoria quadrangle but farther west these beds are separated by 40 feet of shale. The sandstone of the Trivoli cyclical formation lies directly over the Gimlet limestone in the Peoria quadrangle but to the west there is 10 to 30 feet of intervening shale. An unconformity at this same horizon locally cuts out the limestone near Springfield 65 miles to the south.

REGIONAL VARIATION OF THE STRATA

More or less gradual changes in the lithology and thickness of the Pennsylvanian strata about Peoria appear as they are traced to more distant areas, and to the southwest some of them pinch out entirely. Near Cuba the interval between coals Nos. 5 and 6 diminishes from 50 to 15 feet within one or two miles and the intervening shale and sandstone are locally absent. Near Cuba, coal No. 6 is broken by numerous shale partings and near Pleasantview, 35 miles to the southwest, the next area where its horizon has escaped erosion, it is absent although its underclay and cap limestone are present. Thirty-five miles farther southwest, near Liberty, the underclay and cap limestone, which is lithologically and faunally almost identical to that in the Peoria area, are present but coal No. 6 is not developed. Throughout a considerable area in Fulton and adjoining counties a nodular fresh-water limestone occurs between the underclay of coal No. 6 and the sandstone below. In one small area east of Cuba a thin limestone with marine fossils occurs in a somewhat similar position. This is the only known occurrence of a marine bed in Illinois which does not almost immediately overlie a coal horizon.

The beds associated with coal No. 5 retain almost identical characters between Peoria and Cuba and are quite similarly represented near Pleasantview. Coal No. 5, like coal No. 6, pinches out to the southwest. It is present with normal thickness at Pleasantview nearly 40 miles beyond the border of coal No. 6 but is missing from the Liberty section where its cap limestone, locally reduced to discontinuous boulders and nodules, directly overlies the underclay. Not only have both coals pinched out in the Liberty area but the intervening shale and sandstone has also disappeared. An irregular fresh-water limestone, divided by shale into four beds, occurs at many places beneath the underclay of coal No. 5.

The strata between coals Nos. "4" and 5 have been traced almost continuously from Peoria 100 miles southwestward to Liberty and 50 miles northwestward to Galesburg. This series of strata is peculiar in that no sandstone is present anywhere in the area. Coal "No. 4" commonly attains a thickness of only a few inches although it locally thickens to several feet.

The overlying dark shale is characterized in at least seven quadrangles by large smooth pyritic and calcareous concretions with a characteristic fauna. Beneath the underclay of coal "No. 4" occurs a fresh-water limestone which is persistent through most of the area studied. At one locality an unconformity at the base of the coal cuts out the beds down to the upper part of the underlying sandstone.

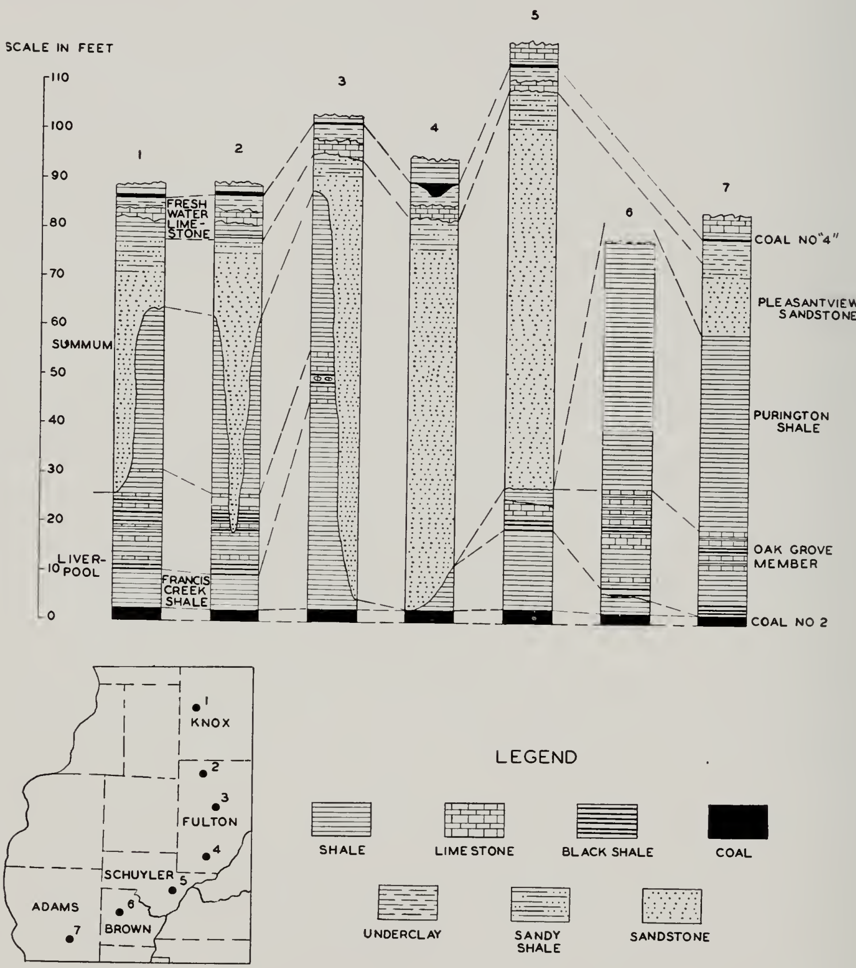


FIG. 40. Geologic sections of lower Carbondale strata between coals Nos. 2 and 4, from Galesburg, Knox County, to Liberty, Adams County.

Outcrops of Pennsylvanian strata are small and scattered and there are numerous areas where no exposures occur, owing to the thick mantle of glacial drift in western Illinois. Such diagnostic features as the various parts of the section possess are therefore very important for local correlation.

DIAGNOSTIC CHARACTERS OF MEMBERS

The coals may be recognized by thickness, characters of bedding, and the nature of over- and underlying beds.

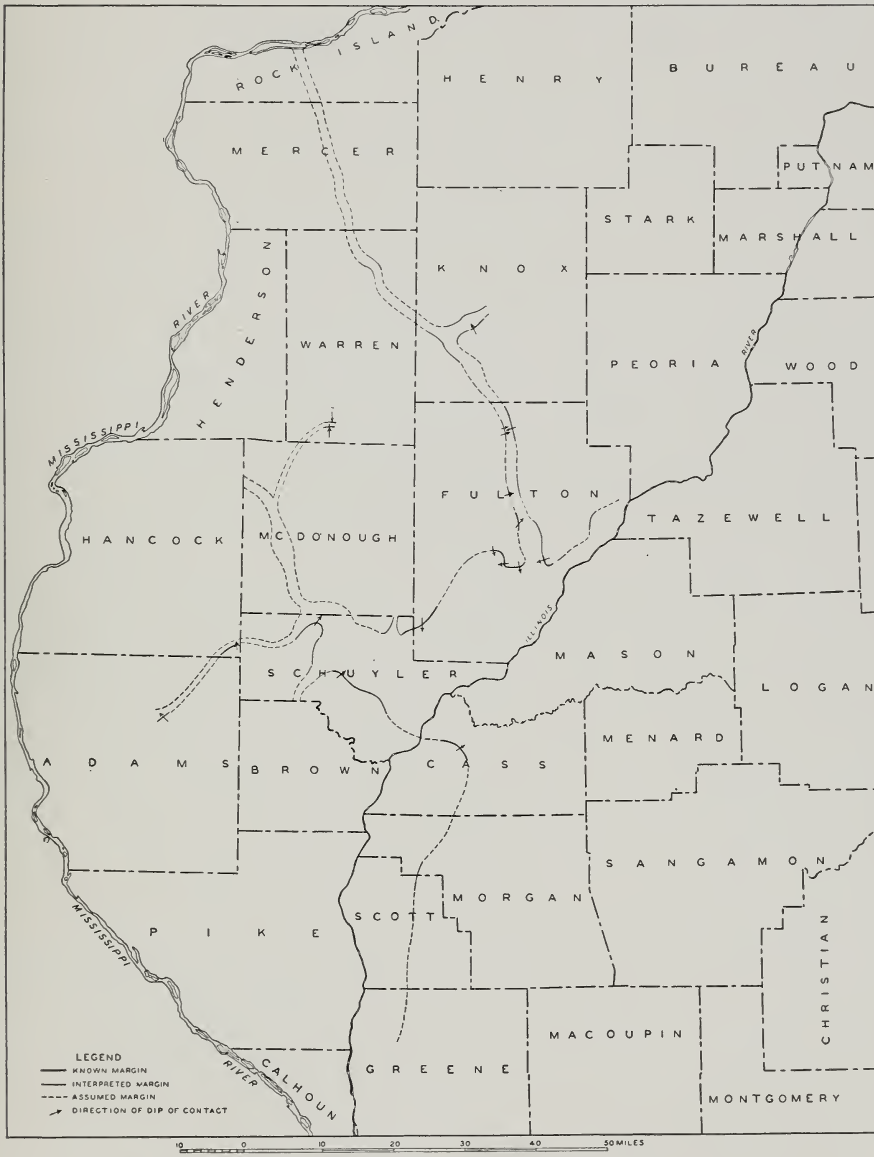


FIG. 41. Map showing position of channels which contain basal sandstone of the Summum cyclical formation. (Ekblaw, Sidney, Stratigraphic relations of the Pleasantview sandstone in western Illinois: University of Illinois, Master's thesis, 1930.)

Limestones are identified by color, purity, texture, thickness, and fossils.

The sandstones locally occur in channels or valleys eroded into the underlying beds. In channel phase they are variable in thickness, irregularly cross-bedded, and contain massive lenticular beds. They are coarser below than above and contain conglomerates of locally derived pebbles and more or less abundant carbonaceous material. In nonchannel phase they are thinner and more uniform, finer grained, and more evenly bedded. The sandstones are most satisfactorily identified by their associated beds but certain characters such as thickness, abundance of carbonaceous material, presence of conglomerates, and conspicuous cross-bedding are locally of value in correlation.

LOWER CARBONDALE STRATA

The Lower Carbondale strata between coals Nos. 2 and "4" form the most conspicuously persistent portion of the Pennsylvanian system in western Illinois (Fig. 40). It lies too low to crop out in the Peoria quadrangle but has been traced almost continuously from Mercer County southeast to Fulton County and thence southwest to Adams County, a total distance of 100 miles. The only irregularity in the succession of strata is a gray shale member which locally separates coal No. 2 from its overlying hard, black, laminated shale. Otherwise this interval exhibits the same type of cyclical succession of beds shown about Peoria.

The most conspicuous member occurring between coals Nos. 2 and "4" is the basal sandstone of the Summum cyclical formation. It is notably unconformable on the beds below and occupies a number of long narrow converging channels eroded to depths between 50 and 100 feet (Fig. 41). These channels vary from a quarter of a mile to 8 or 10 miles in width. Their lateral slopes are steep, ranging from 25° to 40° (Fig. 42). The channels were mainly eroded in the underlying shale but locally the unconformity cuts through the marine limestone bands, and the sandstone rests upon coal No. 2. One place has been observed where the erosion proceeded still deeper and the coal was removed. So far as is known the unconformities beneath all of the other sandstones are similar in nature.

The marine limestone above coal No. 2 is divided into several beds by thick partings of shale (Fig. 43). This series of limestone bands provides the most striking evidence of widespread uniformity in sedimentation. Each of the limestone bands and intervening shale beds possesses distinctive lithologic and faunal characters and occurs in the same order and with nearly the same thickness from Mercer County southeast to Fulton County and from there southwest to Adams County.

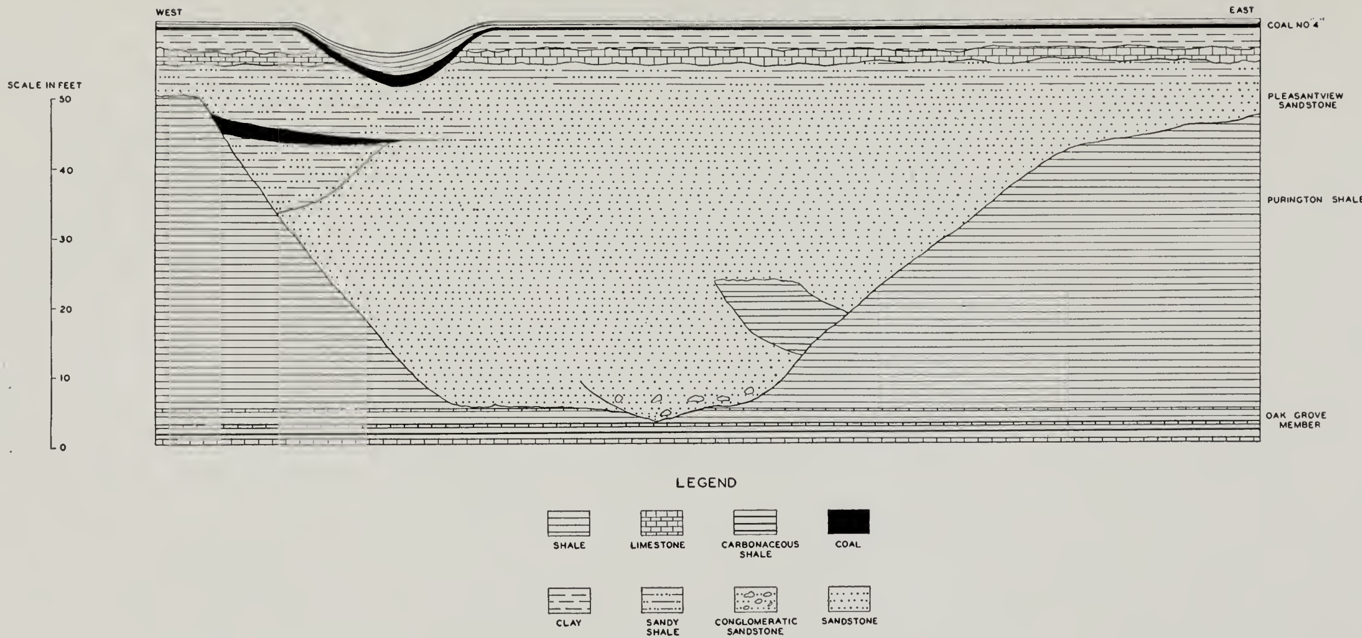


FIG. 42. Cross-section of channel filled with the basal sandstone of the Summum cyclical formation, near Fairview, Fulton County.

POTTSVILLE STRATA

The Pottsville strata exhibit a similar cyclical repetition of beds but most the of cyclical formations into which they are divisible are very thin (Fig. 44) and the upper or marine portions are commonly poorly developed. Consequently the variation of only a few feet in the thickness of the members introduces irregularities that are comparatively greater than those of the higher formations.

In western Illinois, the Pottsville contains coal at eight horizons. Underclays are present beneath all of these horizons and beds carrying marine

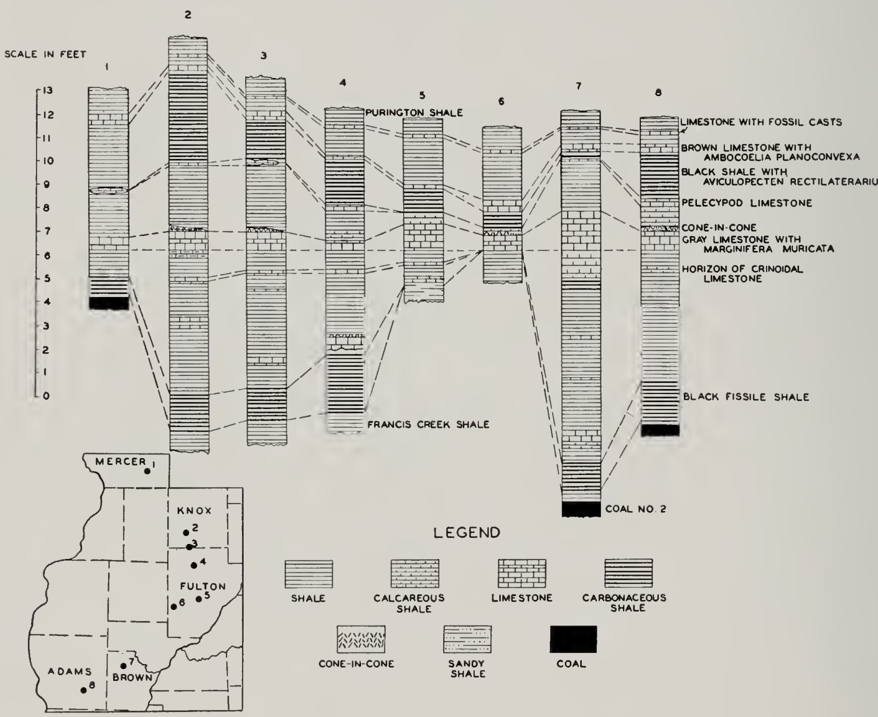


Fig. 43. Geologic sections of the marine limestones and dark shales of the Liverpool cyclical formation (above coal No. 2) from Viola, Mercer County, to Liberty, Adams County, Note the wide persistence of the thin bands of limestone.

fossils have been observed above all but two of them. Unconformable sandstones occur in all but one of the intervals between the coal horizons.

The section is as follows:

Liverpool cyclical formation containing coal No. 2
Greenbush cyclical formation
Wiley cyclical formation
Seahorne cyclical formation
DeLong cyclical formation

Bernadotte cyclical formation
Seville cyclical formation containing coal No. 1
Pope Creek cyclical formation
Babylon cyclical formation

The Liverpool cyclical formation also includes coal No. 2 and its overlying limestone bands and shale which are included in the lower Carbondale

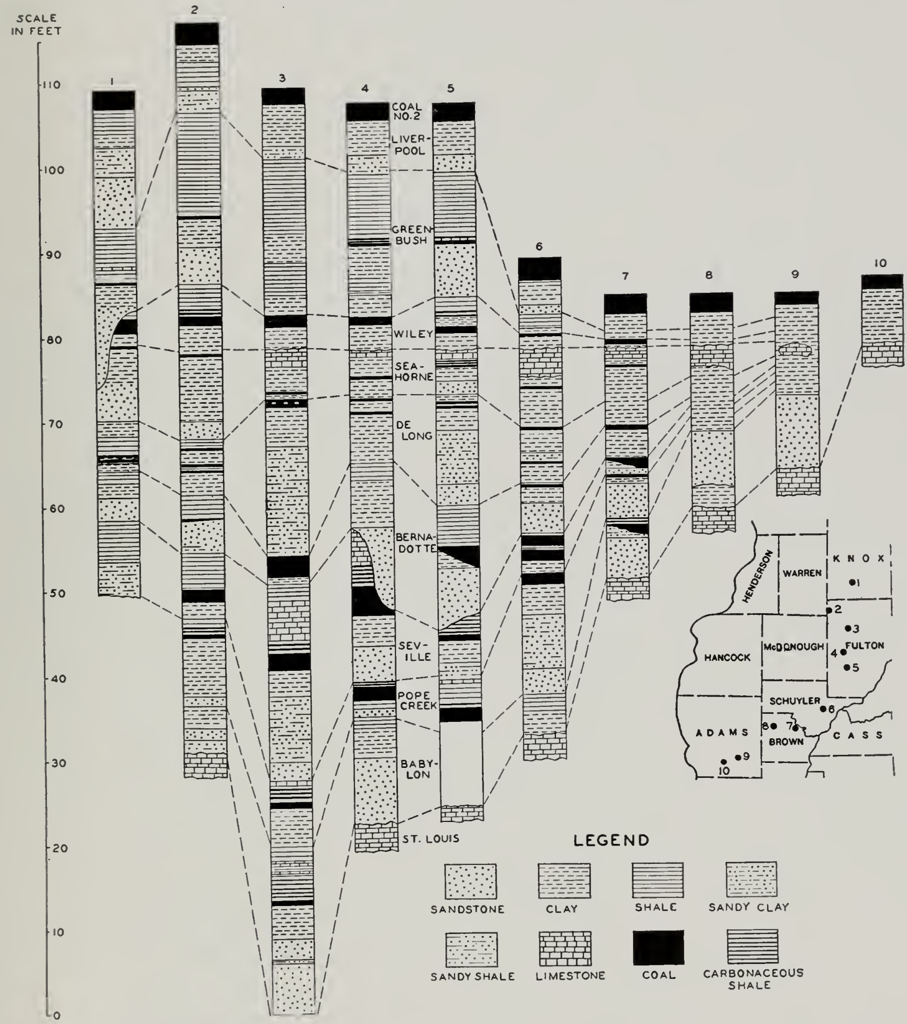


FIG. 44. Geologic sections of the Pottsville strata between Abingdon, Knox County, and Liberty, Adams County.

part of the Pennsylvanian system. Below the basal sandstone of this formation is an unconformity comparable in magnitude to that below the Summum cyclical formation. Channels were eroded at this horizon to a depth of 60

FIG. 45. Typical sections of the fifteen proposed cyclical formations of the Pennsylvanian system as developed in western Illinois.

to 80 feet and locally several of the thin Pottsville cyclical formations have been completely cut out and at one place all of them are believed to have been removed so that the basal sandstone of the Liverpool cyclical formation rests directly upon the Mississippian limestone.

The Greenbush, Wiley and Seahorne cyclical formations are widely present with fair regularity from near Galesburg to Summum. In this part of the section the Wiley cyclical formation is irregular in that it is not known to possess either higher marine beds (although dark shales locally overlie the coal) or a basal sandstone. South of Summum the marine beds and basal sandstone of the Greenbush cyclical formation disappear and the Greenbush and Wiley coals pinch out so that only underclay is present between the base of the Liverpool cyclical formation and the limestone of the Seahorne cyclical formation.

The cyclical formations below the Seahorne are considerably more irregular than those of the upper Pottsville. To the south the various members of these formations, with the exception of the underclays, disappear and the entire Pottsville section beneath the Liverpool cyclical formation is represented by thick underclay with a sandstone at the base and the Seahorne limestone in the upper part. Still farther south the Seahorne limestone pinches out and the combined underclays constitute the Cheltenham fireclay of the St. Louis district.

Coal No. 1 in the Seville cyclical formation is the only commercially important Pottsville coal but it is rather irregularly developed. The most persistent coal is the Wiley which is 6 to 24 inches thick over a wide area. The coal of the DeLong cyclical formation occurs in one to three thin beds separated by clay. Coals are generally absent in the other cyclical formations and where present are usually less than two feet thick.

The thickest Pottsville limestone is that which occurs in the Seville cyclical formation. This bed attains a thickness of 30 feet and although not continuously present it occurs with nearly identical lithology at many places between Mercer and Fulton counties. The most uniform and persistent limestone is that of the Seahorne cyclical formation which varies from one to six feet in thickness and is characterized by a distinctive fauna. The limestone of the Greenbush cyclical formation is also rather persistent but its thickness rarely exceeds six inches. No limestone has been observed in the Wiley and DeLong cyclical formations and in the other formations the limestone member is only thinly developed and locally present.

The Pottsville sandstones differ among themselves in greater degree than do those of the higher Pennsylvanian formations. They are present in all of the cyclical formations except the Wiley and in each case evidence of the unconformable relation to lower beds has been recognized. The sandstone of the Liverpool cyclical formation resembles the higher Pennsylvanian beds

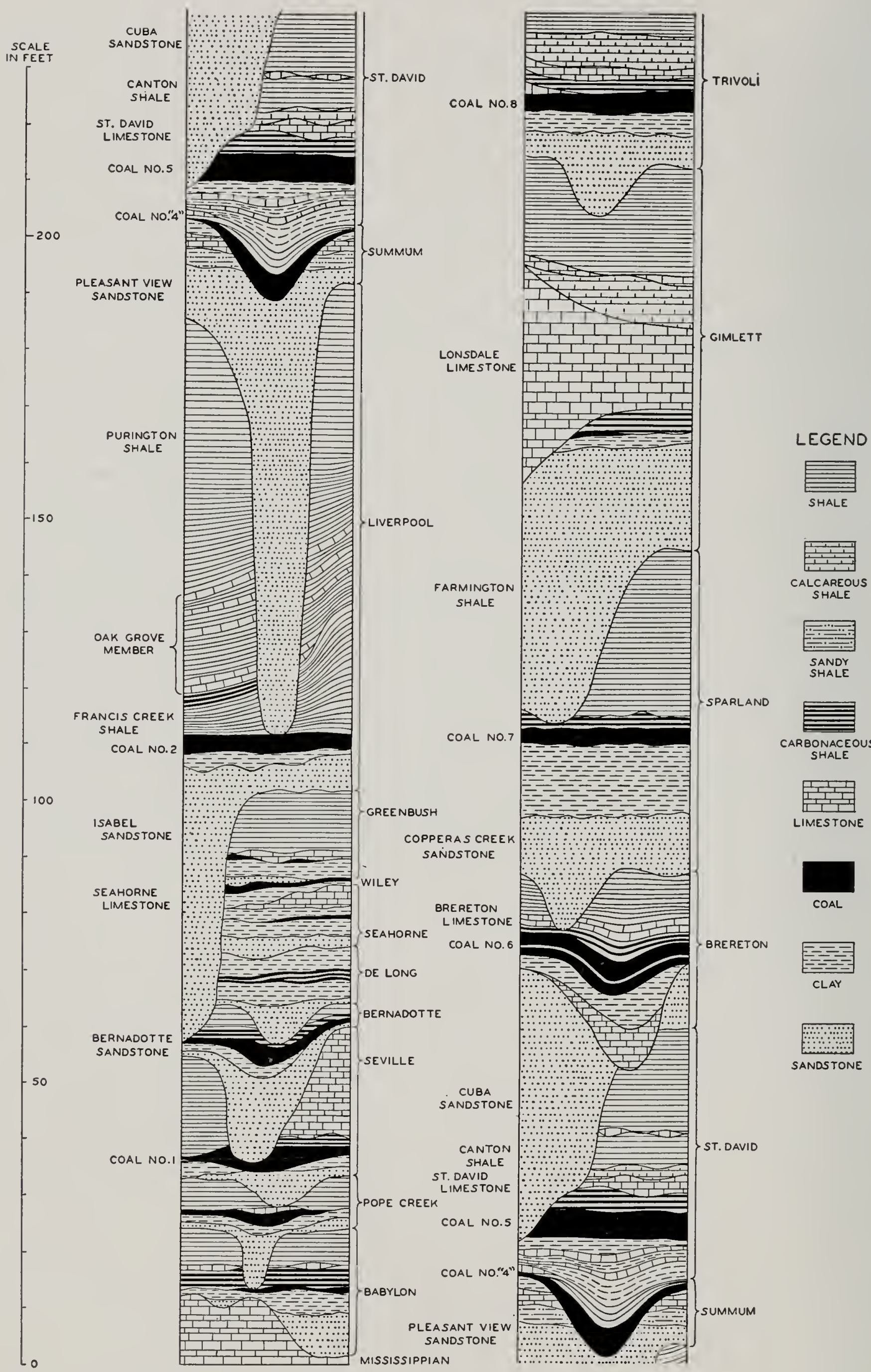


FIG. 46. Generalized section of the Pennsylvanian strata west of Illinois River, divided into the proposed cyclical formations.

and differs from the others of the Pottsville in having locally greater thickness and a greater amount of ferruginous material and also in being coarser than most of the others. The sandstone of the Seahorne cyclical formation is the finest grained of the Pottsville sandstones; that of the Bernadotte is quartzitic and that of the Babylon is composed of large recrystallized grains.

SUMMARY

The Pennsylvanian system in western Illinois is recognized as being divisible into fifteen cyclical formations each of which is composed of similar members arranged in the same order (Fig. 45). A coal bed is at least locally present in each cyclical formation. Four of the coals are of workable thickness and six others are 12 inches or more thick. Underclays are present at most localities in all of the formations and each underclay shows with greater or less perfection a series of zones comparable to a poorly drained soil profile. Marine limestones are present above the coal horizons in twelve of the cyclical formations and a shale with marine fossils overlies the coal of one of the three remaining formations. Sandstone forms the basal member of all but two of the formations and each basal sandstone lies unconformably upon the lower beds (Fig. 46).

PENNSYLVANIAN CYCLES IN OHIO

By Wilber Stout[1]

INTRODUCTION

In Ohio the rocks of the Pennsylvanian system were, for the most part, laid down under quiet water conditions and for that reason are conspicuously uniform and orderly in arrangement. They were deposited in the extensive Appalachian geosyncline far from the source of the siliceous sediments, which was mainly old Appalachia to the east. On this account the system as a whole in Ohio is marked by an abundance of the finer silts, such as clays and shales, and by many limestones, both marine and fresh water. The Pennsylvanian strata contain less coal and much less sandstone but more clay, shale, and limestone than are found to the east and south in Pennsylvania, West Virginia, Kentucky, and Tennessee. Further, the coals in Ohio are more closely spaced throughout the entire column than they are elsewhere in the Appalachian field. In these respects our Pennsylvanian system also differs from that in Illinois, western Kentucky, and Iowa. Thus in Ohio the Coal Measures strata are characterized by the abundance of fine grained sediments, by the uniformity of deposition, and by their continuity over large areas.

GENERAL FEATURES OF THE PENNSYLVANIAN SYSTEM

The Pennsylvanian system of rocks covers an area of 12,339 square miles in the eastern and southeastern parts of the State. The maximum length is

TABLE 8.—*General features of the Pennsylvanian system in Ohio*

System	Series	Area of outcrop in square miles	Thickness in feet	Number of coal beds	Number of marine limestones	Number of marine iron ores	Number of brackish water strata	Number of fresh water limestones	Number of prominent sandstones and conglomerates	Number of prominent clay beds of ceramic importance
Permian.....		1,212								
Pennsylvanian	Monongahela.	1,830	248	7	0	0	0	6	6	0
	Conemaugh...	3,272	400	12	6	0	0	7	8	1
	Allegheny	2,540	212	13	5	2	0	3	4	6
	Pottsville.....	3,485	256	12	5	3	4	0	3	6
		12,339	1,116	44	16	5	4	16	21	13

[1] State Gelogist of Ohio, Columbus.

approximately 225 miles and the greatest width about 75 miles. Bordering Ohio River the Pennsylvanian rocks are overlain by a narrow strip of Permian deposits over an area of 1,212 square miles. Some of the various features of the Pennsylvanian system are shown in Table 8.

CYCLES IN THE PENNSYLVANIAN SYSTEM

The geologist studying the Pennsylvanian system of rocks in the field discovers that an outstanding feature is the repetition of the same grouping of beds, which are arranged in an orderly way as to kind and position. Coal and its associated beds are regularly repeated in a rhythmic or cyclical order throughout the entire Pennsylvanian section, although the order in the Pottsville series is not the same as that in the Monongahela. In these cycles, coal, the outstanding bed, is followed by clay, limestone, shale, sandstone, and iron ore. Such cycles may be considered to include all the strata from the base of one coal bed to that of another. It is true that this arrangement is somewhat arbitrary, as would be the division elsewhere in the cycle for the reason that no regional breaks or disconformities during the deposition of the entire Pennsylvanian strata are evident. The intervals of separation of one coal bed from another in the different series are shown in Table 9.

TABLE 9.—*Intervals between coal beds*

Monongahela series		Conemaugh series		Allegheny series		Pottsville series	
Feet	*Inches*	*Feet*	*Inches*	*Feet*	*Inches*	*Feet*	*Inches*
14	8	19	0	9	3	15	0
39	5	17	0	39	0	32	0
110	2	69	0	29	6	15	0
23	1	34	1	18	0	18	6
33	5	20	5	14	6	9	0
25	7	54	6	13	4	11	6
		26	0	5	4	28	0
		29	0	21	4	20	6
		30	0	9	0	29	0
		47	0	17	0	17	3
		11	0	2	0	10	3
		11	0	31	0	32	0
		35	0				
(Average interval)							
41	1	31	0	17	5	19	10

Forty-five coal beds occur in the 1,096 feet 7 inches of Pennsylvanian strata. The average interval between two adjacent coal beds is 25 feet 6 inches. The longest interval is 110 feet 2 inches and the shortest is 2 feet. The Pottsville and Allegheny coals are somewhat more closely spaced than the Conemaugh and Monongahela coals, the interval in the former two averaging 18 feet 8 inches and in the latter two 34 feet 2 inches. This brings out the rather uniform frequency of coal-forming conditions during the Pennsylvanian period.

General Changes in Character of Deposits

In ascending from the lower portion of the Pottsville series to the upper part of the Monongahela the difference in the character of the deposits is marked; the limestones change from marine to fresh water, the clays in general become thinner and less pure, the coals change somewhat in quality, and the shales change in color, texture, and composition. The gradational variations are due to the fact that many beds in the lower part of the Pennsylvanian system are of marine origin whereas those in the upper part are entirely of fresh water derivation. This change is so great that all kinds of strata are affected to some degree.

The best coals from the standpoint of quality belong to the Pottsville series and the poorest, possibly, to the Conemaugh. The older coals contain less ash and sulphur than the younger ones but are not necessarily thicker or more persistent. These changes appear to be due to differences in deposition and, in part, to modifications in the plant life. In the character of the coal beds, however, no sharp separation of the Pennsylvanian system is possible.

Clay of some kind and of some thickness is found below every coal throughout the entire system. The high-grade coal formation clays, those of best ceramic value, are in the Pottsville and Allegheny series, or that portion of the Pennsylvanian section between the Sharon and Strasburg coals. This part is below the first fresh-water limestone, which occurs at the base of the Middle Kittanning coal. In this portion is found not only the purest plastic clays but also the most refractory flint and semi-flint clays. Clays of somewhat less ceramic value are present in the upper Allegheny and lower Conemaugh series, or between the Strasburg coal and the Ames limestone. Throughout this part of the section, where both marine and fresh-water limestones are present, the clays are generally contaminated with more or less calcareous matter. In Ohio, no clays above the Ames limestone are worked. This part of the Pennsylvanian system is entirely of fresh water origin, the clays are calcareous and in many cases only a few inches thick. Thus on the basis of clays, the system may be divided into three parts.

The limestones throughout the column also indicate a three-fold division. The limestones and fossil-bearing calcareous shales are of marine or brackish water origin, from the Harrison member to the Strasburg coal; are of either marine or fresh water origin from the Strasburg coal to the Skelley limestone;

and are entirely of fresh water origin from the Skelley limestone to the Waynesburg coal. The gradation is thus from marine origin, through marine and fresh water, to fresh water origin alone. If any division of the Pennsylvanian system into large units is to be made, this one seems to be the most logical.

The bedded iron ores, confined mostly to the Pottsville and lower Allegheny series, bear marine fossils which show the origin of the members. Usually the fossils are few in number and are rather diminutive in size, due to impoverishment. In the upper formation the iron matter is concentrated only as small concretions in the shales. These occasionally yield plant fossils. The shales in the lower part of the Pennsylvanian system are bluish-gray in color but those in the upper part vary from light gray through drab, brown, green and pink, to deep red. The composition and texture also change somewhat from the older to the younger strata. The sandstones show little variation in ascending order except that they become somewhat more micaceous and have less argillaceous bond.

On the basis of such data the Pennsylvanian system may be divided as follows:

3. *Upper division.*—Strata from the top of the Skelley limestone to the top of the Waynesburg coal; the beds appear to be entirely of fresh-water origin.

2. *Middle division.*—Strata from the top of the Strasburg coal to the top of the Skelley limestone; in this section both marine and fresh water strata are prominent.

1. *Lower division.*—Strata from the Harrison ore to the top of the Strasburg coal; throughout this part of the column marine deposits are very prominent.

From the changes and gradations thus shown in the Pennsylvanian system in Ohio it is quite evident that a cycle in one part of the system will be somewhat different in detail from that in another. Changes in the character of deposition or incompleteness of the cycle may cause variation within a succession of beds in any given division.

LOWER DIVISION

In the lower division or the Harrison-Strasburg section, three kinds of cycles may be recognized which at most are not radically different from each other. They are, however, quite different from others higher in the geologic column. The complete cycles in the lower division of the Pennsylvanian system are listed below:

(A)

Clay, fresh-water origin, generally good quality
Shale and sandstone, largely marine

Iron ore, marine
Limestone, marine
Coal, fresh-water

An example of such a cycle is as follows:

Clay, Upper Mercer
Shale and sandstone
Ore, Lower Mercer
Limestone, Lower Mercer
Coal, Middle Mercer

In the lower division this cycle is also repeated with the Bedford and Clarion-Scrubgrass coals.

(B) The second type of cycle, which is by far the most common, contains all the strata in (A) except the iron ore. It contains the following beds:

Clay, fresh-water, generally good quality
Shale and sandstone, mainly marine
Limestone, marine
Coal, fresh water

This cycle is repeated in the lower division with the Sharon, Vandusen, Lower Mercer, Brookville, and Lower Kittanning coals and also again in the middle division. It is the distinctive cycle. The following is an example:

Clay, Ogan
Shale and sandstone
Limestone, Putnam Hill
Coal, Brookville

(C) In a few cases at the close of coal deposition, the inundation was less complete, producing only brackish water instead of marine conditions. In such waters no limestone was produced but shale containing a brackish-water fauna is present just above the coal. The material is usually a hard bone shale with much carbonaceous matter. Under such conditions the cycle is as follows:

Clay, fresh-water, generally good quality
Shale and sandstone, probably brackish water or marine
Shale, fossiliferous, brackish water
Coal, fresh-water

In the lower division such an orderly arrangement of beds occurs with the Anthony, Quakertown, Bear Run, Upper Mercer, Tionesta, and Winters coals. A typical example is given below:

Clay, Quakertown
Shale and sandstone
Shale, carbonaceous, with brackish-water fauna
Coal, Anthony

These three types of cycles (A, B, and C) may all be repeated in the overlying or middle division of the Pennsylvanian system but none of them is present in the upper division. They all depend on either a marine or a brackish water condition during a part of the cycle. As stated above, the general conditions of deposition during this time were such that their influence was reflected in modifications also of the clays, coals, and even shales.

MIDDLE DIVISION

In the middle division of the Pennsylvanian system, that is, from the Strasburg coal to the Skelley limestone, both marine and fresh-water beds are prominent. It represents a transition stage between predominant marine conditions in the lower part of the system and truly fresh-water conditions in the upper part. On this account the middle division contains cycles peculiar to itself, some typical of the lower division and others characteristic of the upper division. The cycles most pronounced are listed below:

(D) The one cycle really peculiar to the middle division is that in which both a marine and fresh-water limestone are present. The other elements, clay, coal, and shale, more commonly resemble strata in the upper than in the lower division. The beds in this cycle are as follows:

Clay, thin, impure, fresh-water
Limestone, fresh-water
Shale and sandstone, partially marine
Limestone, marine
Coal, fresh-water

The best examples of this cycle are found with the Middle Kittanning, Wilgus, Anderson, and Duquesne coals. The following is representative:

Clay, Anderson
Limestone, Bloomfield
Shale and sandstone
Limestone, Cambridge
Coal, Wilgus

(B) In this division is also present Cycle B which is so well represented in the lower division of the Pennsylvanian system. Such groupings are found associated with the Brush Creek and Harlem coals. The strata with the former are as follows:

Clay, Wilgus, fresh-water
Shale and sandstone, probably marine
Limestone, Brush Creek, marine
Coal, Brush Creek, fresh-water

(E) In this transition part of the column, that is the Strasburg-Skelley interval, there appears another cycle which is wholly of fresh water origin and which is characteristic of the upper division of the Pennsylvanian system. During such a period deposition was entirely continental. The elements of such a cycle are as follows:

Clay, fresh-water
Limestone, fresh-water
Shale and sandstone, fresh-water
Coal, fresh-water

Completed cycles of this character are present with the Upper Kittanning and Upper Freeport coals. Others less perfect occur with the Lower Freeport, Mahoning, and Barton coals. With the latter, however, the limestone is not so definitely concentrated into beds but is more of the marly type present in the clay.

The middle division thus contains only one distinctive cycle, that in which occurs both a marine and a fresh-water limestone, as previously shown. Other changes, however, are evident. Soft red clays, forerunners of thick deposits of such material in the upper part of the Conemaugh series and again in the Dunkard series, are present below the Harlem coal, below the Wilgus coal, and locally even below the Lower Freeport coal. In this division also the siliceous shales change more from the light gray to the yellow and drab shades and the clays from high-grade material of ceramic value to impure deposits of no economic importance.

UPPER DIVISION

In the upper division of the Pennsylvanian system, or from the top of the Skelley limestone to that of the Waynesburg coal, the strata are evidently of continental or fresh-water origin. As a whole, the division is characterized by much fresh-water limestone, by shaly marl, and by calcareous shale. The coals vary from thin to thick and from good to poor. The clays are thin and impure. Several types of cycles are evident but of these only three are prominent and these are listed below:

(E) As previously shown, this cycle begins in the middle division but is rather pronounced in the upper division. It is as follows:

Clay, impure, generally thin, fresh-water
Limestone, fresh-water
Shale and sandstone, fresh-water
Coal, fresh-water

In general, this arrangement of strata is present with the Uniontown coal and in some parts of the field also with the Pittsburgh, Sewickley, and Fishpot members. As should be expected, many lateral variations are present throughout the area, as shale quite frequently is replaced by sandstone or by limestone. An example of this type of cycle is given below:

Clay, thin, Little Waynesburg
Limestone, Waynesburg
Shale and sandstone
Coal, Uniontown

(F) The most distinctive cycle in the upper division of the Pennsylvanian system is that where the interval from one coal bed to another is nearly entirely made up of fresh-water limestones and calcareous shales. Great masses of calcareous strata are common to the Monongahela series in eastern Ohio. The order is as follows:

Clay, thin, local, fresh-water
Limestone and calcareous shale, fresh-water
Coal, fresh-water

In eastern Ohio this succession is found with the Pittsburgh, Redstone, and Sewickley coals and locally with other beds. An example is given below:

Clay, thin, local, Fishpot
Limestone and calcareous shale, Fishpot
Coal, Redstone

(G) The next type of cycle is only of minor importance but it occurs occasionally in both the upper and middle divisions. In this the interval between the coal beds is composed almost wholly of normal shale and sandstone sediments. The order of deposition is as follows:

Clay, thin, local, fresh-water
Shale and sandstone, fresh-water
Coal, fresh-water

Such an arrangement is found with the Fishpot and the Little Waynesburg coals. Laterally, however, this cycle may change to another with a fresh-water limestone as a prominent component.

A study of the coal formations thus indicates that several rather broad conclusions may be reached. These are as follows: (1) that the entire Pennsylvanian system in Ohio is made up of cycles or groupings of beds in which coal is the most constant unit; (2) that about seven types of complete cycles with distinctive features are present in the system; (3) that these seven cycles account for all the groupings except for local modifications and for incomplete cycles; (4) that a general progression or change in deposition is evident from the older to the younger beds; (5) that the kind of strata in a cycle varies decidedly with its position in the geological column.

Incomplete and Irregular Cycles

As should be expected with such a repetition of strata, incomplete and irregular cycles occur with some frequency throughout the Pennsylvanian column in Ohio. Most of these are due simply to shifting of the water level through subsidence or elevation, through removal or formation of barriers, through flooding or drought, or other causes. Some abnormal features were probably caused by sedimentation on the old surface. At one place the conditions may have been favorable for the deposition of shale whereas at another they were such that limestone was the dominant sediment. Slight disconformities owing to current action and to local elevation also give rise to minor disturbances in the rock strata.

For example, the Huckleberry clay and coal were deposited soon after the Sciotoville clay and Anthony coal. The variation in the swamp floor was such that the two groups in places coalesce. Under such conditions and where the Anthony coal is a mere soot streak or absent, the two clays appear as one bed with the Huckleberry coal appearing to be the coal associated with the Sciotoville clay. The Zaleski member offers another example of an incomplete cycle. In this case the deposition of the Ogan coal was brought to a close by a marine inundation that gave rise to the Zaleski flint member. Then instead of further subsidence with the deposition of shale and sandstone there was a slight elevation of the floor or a withdrawal of the water, thus establishing swamp conditions again during which time the Winters clay and coal were formed.

In Ohio the Scrubgrass coal is just a phase of the Clarion member for the Scrubgrass bed has no clay associated with it and is separated from the Clarion by bony, carbonaceous shale of the algal or open water type. The marshes giving rise to the Clarion coal were submerged by shallow open waters, thus allowing the accumulation of the bony, carbonaceous shale. Then after prolonged sedimentation or because of some other factor which caused a decrease in the water level, the floor again became fit for the growth of plant life, the result of which was the Scrubgrass coal.

One of the prominent examples of an incomplete cycle is associated with the Lawrence coal. The underlying Clarion cycle is an orderly succession with, in ascending order, Clarion coal, Vanport limestone, ferriferous ore, shale and sandstone, and Lawrence clay. The Lawrence coal overlying this clay is poorly developed, often being only a mere soot streak and frequently being represented by a thin layer of dark-colored flint clay which denotes extensive chemical action or a phase of weathering. Above the Lawrence coal the normal members of the cycle, marine limestone, iron ore, and shale and sandstone, are absent so that the Lower Kittanning clay lies on the Lawrence coal or, in the absence of the Lawrence coal, on the Lawrence clay. Thus the great bed of clay of so much ceramic value and which is usually considered as a unit is in reality two clay beds coalesced because of an incomplete cycle.

Incomplete and irregular cycles somewhat similar to that just cited are present in the Lower Kittanning-Strasburg, Bolivar-Upper Freeport, and Fishpot-Sewickley intervals. The effects of slight changes in depositional conditions are shown by such examples as the regular clay parting in the Lower Kittanning coal, as a lens of coal in the Pittsburgh limestone, as a hard bone shale layer in the Sewickley coal, and as a limestone stratum in the Uniontown coal.

Disconformities

No regional disconformities are evident at any position in the Pennsylvanian system in Ohio. Even its separation into series, as now used, is purely an arbitrary division based almost entirely on the thickness of certain coal beds and not on definite interruptions in the processes of sedimentation.

The various strata were laid down in an orderly way with little cessation at any time of the normal processes. The few breaks are minor and local. Some local disconformities are present at the base of some coal formation sandstones, but with few exceptions these may be accounted for by scour from current action rather than by uplift and surface erosion. Laterally these sandstones dovetail and interbed with shales and soon give way entirely to the finer silts. The sandstone members in Ohio are by no means continuous sheet deposits. The most prominent sandstones are replaced many times and over wide areas by shales in which no erosional surfaces or breaks of any kind are evident. Sandstones were being deposited in one part of the basin and shale in another, the kind depending upon the depth of water, the strength of current, the proximity to the source of the material, et cetera. Where present in Ohio, these disconformities are small, never replacing any considerable thickness of strata. In this State the evidence does not favor the interpretation of a repeated oscillation of the floor from one extreme, where surface erosion was effective in producing disconformities, to another, where depositional forces were active in building up additional beds.

Subsidence

The important diastropic change during Pennsylvanian time in Ohio was one of general and regional subsidence at a slow but variable rate, as shown by the recurrence of the cycles. Submergence is evident during the deposition of the great body of shales, sandstones, limestones, and iron ores. Land conditions were most nearly approximated during the accumulation of the clays and the coals. The regional extent of the downward movements is shown by the continuity of the members. For example, the Mercer limestones and coals, although thin, have a great sweep from western Pennsylvania across Ohio and far into Kentucky. The Ames, Vanport, and Brush Creek members are recognized over a wide area. Even fresh-water limestones such as the Pittsburgh, Fishpot, Benwood, and Uniontown, are now traced over thousands of square miles. The Lower Kittanning clay, which is so prominent for its ceramic value, is worked along an outcrop of more than 600 miles throughout which it maintains great persistency and regularity. The thin partings in the Pittsburgh coal are easily recognized throughout most of the workable field of more than 6,000 square miles. Detailed work has thus shown various Pennsylvanian strata to be remarkably continuous throughout the field.

The movements of subsidence were probably rather sudden, more that of rigid bodies than of flexible ones. The weight of sediments within the basin was probably the main cause of the strains which were relieved by subsidence of the basin and elevation of the adjacent uplands. The downward movements were not large, inasmuch as the cycles are repeated at short intervals throughout the entire system. The submergence in each cycle took place just after coal deposition or rather it brought to a close the accumulation of vegetable matter. The rapidity of the subsidence is shown by the fact that most of the massive limestones lie directly on coal beds or are separated from them by only thin layers of fossiliferous shale. The sharp contact of the coal with the overlying bone shale, gray shale, or fresh-water limestone also indicates rather rapid downward movement. A study of the coal formations in the Pennsylvanian system of Ohio therefore leads to the conclusion that there was a general sinking of the basin as a whole but that the movements of rather rapid subsidence were followed by periods of rest, this repeated over and over for each succeeding cycle.

Conditions of Deposition

COAL

The conditions under which the coal beds were formed need little discussion here as the subject has been ably treated by David White, Reinhardt Thiessen, A. C. Noé, and others. These investigators show that the vegetable matter is derived most largely from the land-loving types of plants and that it was laid down on marshy lands under humid conditions. The deposition of coal requires a rather close adjustment of several factors, hence only a small part of the total vegetable matter of the period was preserved as coal. Indirectly, more of it is represented by the associated clay. The coal beds were deposited just preceding submergence or apparently during a period when there was a very slight subsidence, thus favoring preservation, before the more rapid movement that caused complete inundation and destruction of plant life.

The thickness of the coal depends on the length of time the organic matter escaped destruction, on the rapidity of plant growth, on the type of plant life, and in a minor way on the addition of silty constituents. The great coal beds, like the Middle Kittanning, Upper Freeport, and Pittsburgh, required much vegetable matter and long intervals of time for formation. The mere soot streaks, often present over rather wide areas, represent little except the vegetation that was growing at the time of burial. For example, the Little Waynesburg coal for many miles along its outcrop may be less than one-eighth inch in thickness.

The partings in coal beds are often significant in showing incidents in the formation of the members. The clay partings were formed during periods when the plant life was growing but when it failed to escape oxidation, due to decrease in the humidity, lowering of the water table, et cetera. Such clay strata simply indicate drier conditions than prevailed during coal accumulation. Bone shale partings were formed in shallow waters, largely from algal matter, from macerated plants, and from clastic sediments. They represent slight submergence. The origin of "mother coal" in the coal beds is not well understood. The common opinion is that such mineral charcoal is caused by normal oxidation under restricted conditions of air and moisture. True shale partings are not common in coal beds; in fact, they are of rare occurrence. They denote complete inundation and suspension of the plant growth. Fresh-water limestones and even sandstones occasionally appear as parting materials. Their relation to the coals, however, is simple.

MARINE LIMESTONE

In the Pennsylvanian system in Ohio, the marine limestones are always above the coal beds. Usually such a stratum lies directly on the coal or is separated from it by only a few inches of limy, fossiliferous shale. Where the intervening shale is even several feet thick its marine origin is commonly clear. The marine limestones were laid down in open shallow waters and were formed mainly by precipitation caused by minute organisms extracting carbon dioxide gas from the soluble calcium carbonate $CaH_2(CO_3)_2$. Locally siliceous matter or flint (SiO_2) was formed under somewhat similar conditions. The roof shales above several coal beds contain a brackish-water fauna, showing that the inundation was only partial. Laterally some of the marine limestones develop brackish-water phases. Thus these marine members and also the brackish-water strata were deposited at the beginning of the submergence of the coal formation cycles.

FRESH-WATER LIMESTONE

These limestones were laid down in open, shallow, fresh-water basins where the calcium carbonate ($CaCO_3$) was precipitated largely through the action of plant life. Most commonly such a member lies under the clay or, where the clay is absent, under the coal. The fresh-water limestones thus built up the swamps to such conditions that land plants could take hold for the formation of coal or clay. In a few cases in the Monongahela series all of the submerged part of the cycle is represented by fresh-water limestone, both shale and sandstone being absent. Where the fresh-water limestones are well developed the clays are usually thin or practically absent.

IRON ORES

The regularly bedded iron ores are nearly all of marine origin as shown by the scattered fossils which they bear. The unweathered ore, under deep covering, is of the ferrous carbonate or siderite form ($FeCO_3$). It was chiefly precipitated by the action of bacteria removing carbon dioxide (CO_2)

from the soluble molecule $FeH_2(CO_3)_2$. In the fresh-water formations the iron components are concentrated only to nodules scattered throughout the shales. These concretions are partially secondary in origin as they show growth after the deposition of the shale. In the gray shales the iron in the concretions is mainly siderite whereas in the red clay shales it is commonly hematite. Where these ores are fossiliferous the remains are apt to be bits of plants.

SHALE

The coal formation shales were deposited in quiet and generally shallow waters as is shown by their lamination, fineness of grain, wide distribution, et cetera. In the lower part of the Pennsylvanian system they are largely of marine origin, whereas in the upper part they are of fresh-water derivation. The main source for such silts was the old Piedmont area to the east. Further, the Canadian highlands to the north furnished small contributions as did also the Cincinnati arch to the west. In general, the shales represent part of the cyclical submergence.

SANDSTONE

The sandstones were deposited under much the same conditions and by the same but somewhat more active forces that were instrumental in the formation of the shales. The residues from the uplands were simply differentially sorted by water during transportation and sedimentation, the finer parts being laid down as shale in the quiet waters whereas the coarser parts were deposited as sandstones along the lines of current action. In general, the sandstones appear to have been formed along shore lines. True delta deposits, although not common, are most prominent in the upper part of the Pennsylvanian system or in that part of the section entirely of fresh water origin. In Ohio the sandstones are not widespread sheet deposits like the coals, clays, and limestones, but are much interrupted or broken by broad areas over which even the most conspicuous members are absent. They belong in the same part of the cycles as the shales.

CLAY

Coal formation clay is always directly associated with coal or it marks a horizon on which coal somewhere appears. The relationship is that both required plant life for their formation. Both materials were laid down in forested, marshy lands where the main differences for the formation of one or of the other were changes in the water conditions, in the general humidity, in the temperature, et cetera, thus involving either oxidation or preservation of the organic matter. The clays were formed from the normal fine-grained shale sediments that filtered into the swamps. Such silts were altered slightly through direct action of the living plants but far more through the action of the various organic products of decay. The chemical action is mainly that of hydrolysis, carbonation, hydration, and desilication. In order to make a clay from a shale, much silica, SiO_2, and many bases—ferrous oxide, FeO; calcium oxide, CaO; magnesium oxide, MgO; potassium oxide, K_2O; and soduim oxide, Na_2O—must be removed from the shale, thus leaving a product richer in alumina, Al_2O_3, titanic oxide, TiO_2, and water, H_2O. The main reactions involved are as follows:

(a) With feldspar, not prominent in most silts

$$KAlSi_3O_8 + HOH = HAlSi_3O_8 + KOH$$

$$2KOH + CO_2 = K_2CO_3 \text{ [soluble]} + H_2O$$

$$HAlSi_3O_8 = HAlSiO_4 + 2SiO_2$$

$$2SiO_2 + 2H_2O = 2H_2SiO_3 \text{ [soluble]}$$

$$2HAlSiO_4 + H_2O = H_4Al_2Si_2O_9 \text{ [Kaolinite]}$$

(b) With muscovite, very prominent in all shales

$$KH_2Al_3Si_3O_{12} + HOH = H_3Al_3Si_3O_{12} + KOH$$

$$2KOH + CO_2 = K_2CO_3 \text{ [soluble]} + H_2O$$

$$2HAlSiO_4 + H_2O = H_4Al_2Si_2O_9 \text{ [Kaolinite]}$$

(c) With iron minerals, much removed from shales

$$Fe_2O_3 + CO = 2FeO + CO_2$$

$$FeO + 2CO_2 + H_2O = FeH_2(CO_3)_2 \text{ [soluble]}$$

(d) With lime minerals, usually low

$$CaCO_3 + CO_2 + H_2O = CaH_2(CO_3)_2 \text{ [soluble]}$$

(e) With magnesia, largely as biotite

$$HKMg_2Al_2Si_3O_{12} + 5HOH = H_6Al_2Si_3O_{12} + KOH + 2Mg(OH)_2$$

$$2KOH + CO_2 = K_2CO_3 \text{ [soluble]} + H_2O$$

$$2Mg(OH)_2 + 4CO_2 = 2MgH_2(CO_3)_2 \text{ [soluble]}$$

$$H_6Al_2Si_3O_{12} = H_4Al_2Si_2O_9 \text{ [Kaolinite]} + H_2SiO_3 \text{ [soluble]}$$

(f) With potash and soda, mainly in muscovite, reactions given under (b).

All gradations of clay from a slightly modified shale to a high-grade flint clay are present in the Ohio field. An enormous amount of chemical work has been done in best plastic, semi-flint, and flint clays, where the alumina has been raised from about 20 per cent in the shales to more than 30 per cent in clays. These silts were modified almost entirely as they were laid down. The chemical reagents were mainly the various organic acids liberated through decay of the vegetable matter and were active during the entire time of such decay. Clays are not shales purified by the action of the plants that grew on them. There is no relation between the thickness nor the quality of the coal and that of the underlying clay. A thick coal bed may have a thin clay or vice versa. The best clays are found in the lower part of the Pennsylvanian system where much of the strata is of marine origin and where, during clay deposition in the fresh-water marshes, the circulation of water was sufficient to remove the soluble silica and bases liberated by the chemical reactions.

Moreover, clay deposition was longer, or thicker beds were built up, during Pottsville and Allegheny time than during Conemaugh and Monongahela time. A study of the conditions thus leads to the conclusion that clays were slowly built up from shale sediments, that they were deposited in marshy

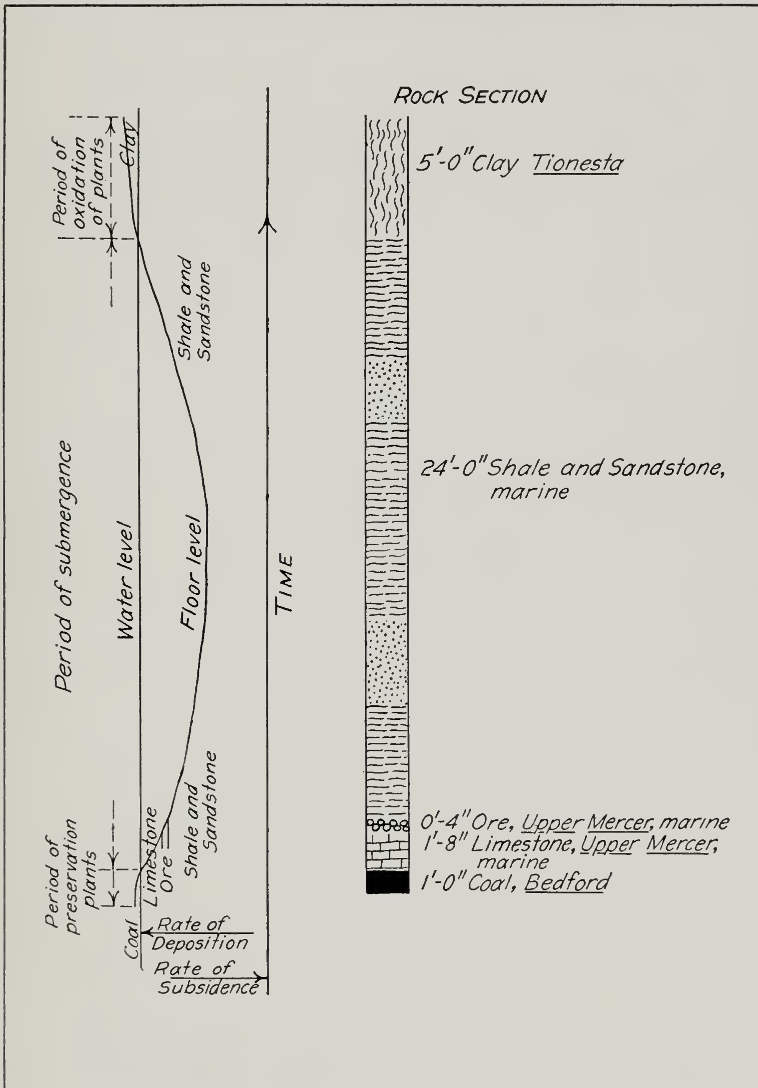


Fig. 47.

areas closely approximating that of coal, and that the chemical agencies were supplied by the destruction of vegetable matter. Clay then occupies a position in the cycle much the same as that of coal.

CONCLUSIONS

In Ohio the coal formation cycles are very prominent throughout the entire Pennsylvanian system and also in the overlying Dunkard. In general, the cycles are completed, the strata being on the average about 26 feet thick.

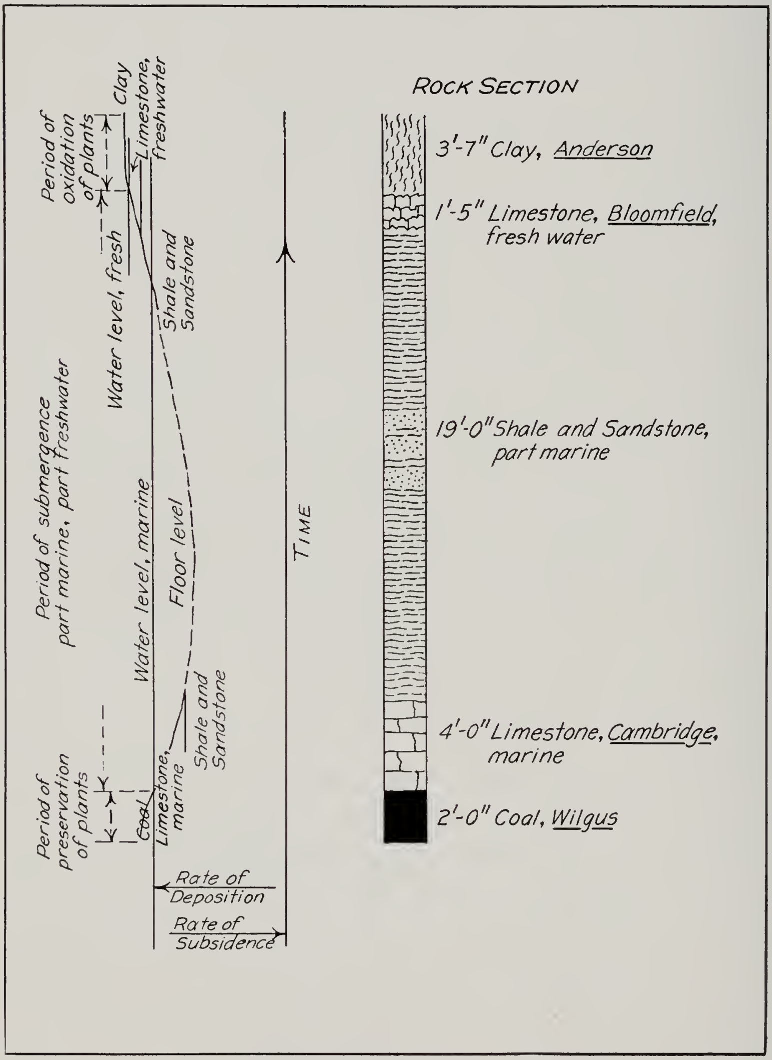


FIG. 48.

The kinds of strata composing the cycle depend on the location of the cycle in the Pennsylvanian system or on the dominant marine or fresh water conditions under which the beds were deposited. The general crustal movement during the formation of the entire system was one of regional and not local subsidence. No disconformities due to elevation and widespread erosion are anywhere apparent. The movement was one of slight but rather rapid depression, followed by a pause, this order being repeated over and over for each succeeding cycle. The surface throughout the great Appalachian syn-

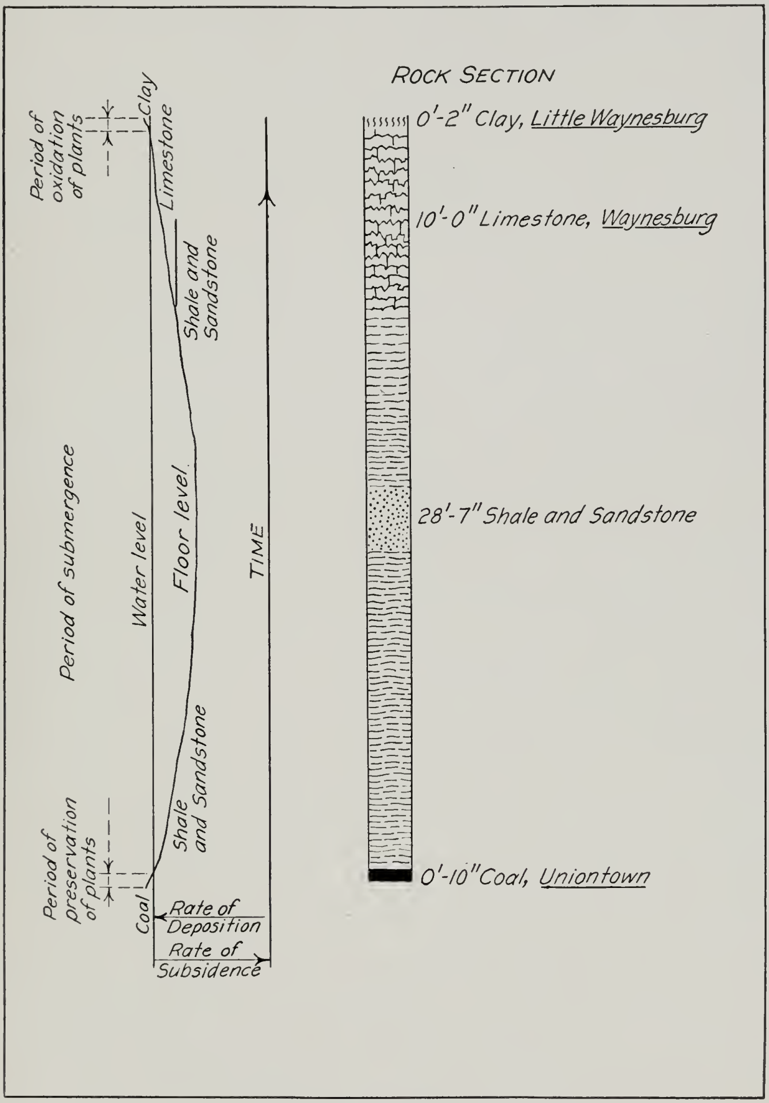


Fig. 49.

cline was always quite flat, and was never far above or far below water level. In general, the rate of deposition was slow as indicated by the formation of clay, limestone, and coal. The clastic sediments were derived mainly from the Piedmont area to the east. Coals and clays were formed under somewhat similar conditions except that in the coals the vegetable matter was partially preserved, whereas in the clay formation, the plant tissue, through decay, gave the chemical reagents for the purification of the infiltrated silts to more kaolinitic sediments. The limestones vary from marine to fresh water and are definite aids in tracing the history of Pennsylvanian sedimentation. On the whole, the cyclical formation of the Pennsylvanian system in Ohio is clear and definite.

TABLE 10.—*Generalized section of the Pennsylvanian system of Ohio*

MONONGAHELA SERIES

	Thickness		Interval	
	Feet	*Inches*	*Feet*	*Inches*
Coal, fair purity, *Waynesburg No. 11*	1	4	..	..
Shale and sandstone, *Gilboy*	14	6	16	0
Coal, persistent, *Little Waynesburg*	..	2	..	..
Limestone and marly shale, *Waynesburg*	10	0	..	..
Shale or sandstone, *Uniontown*	28	7	39	5
Coal, *Uniontown No. 10*	..	10	..	..
Shale, siliceous, and limestone, *Uniontown*	5	0	..	..
Sandstone, *Arnoldsburg*	8	0	..	..
Coal, wanting, *Arnoldsburg*	..	..	..	..
Limestone and calcareous shale, *Arnoldsburg*	37	0	..	..
Shale, green, or shaly sandstone, *Fulton*	4	0	110	2
Limestone and calcareous shale, *Benwood*	34	4	..	..
Sandstone, local, *Sewickley*	20	0	..	..
Coal, *Sewickley, Mapletown, Meigs Creek No. 9*	1	10	..	..
Clay shale, calcareous	3	0	..	..
Sandstone, *Lower Sewickley*	19	6	23	1
Coal, persistent, thin, *Fishpot*	..	7	..	..
Limestone and marly shale, *Fishpot*	32	1	33	5
Coal, unsteady, *Redstone, Pomeroy*	1	4	..	..
Limestone and marly shale, *Redstone*	13	0	..	.
Sandstone, local, *Upper Pittsburgh*	9	0	25	7
Coal, persistent, *Pittsburgh No. 8*	3	7	..	..
Total	..	..	247	8

CONEMAUGH SERIES

Clay shale	..	6	..	..
Limestone, irregular, *Upper Pittsburgh*	5	0	19	0
Clay shale	13	5	..	..
Coal, very local, *Upper Little Pittsburgh*	..	1	..	..

	Thickness		Interval	
	Feet	*Inches*	*Feet*	*Inches*
Clay shale	4	6	..	..
Sandstone, local, *Bellaire*	10	0	..	..
Shale, siliceous	2	5	17	0
Coal, seldom present, *Lower Little Pittsburgh*	..	1	..	..
Shale, variable	8	0	..	..
Limestone, *Summerfield, Lower Pittsburgh*	12	0	..	..
Shales, variable	26	0	69	0
Sandstone, local, *Connellsville*	20	0	..	..
Clay shale	2	10	..	..
Coal, local, *Clarksburg*	..	2	..	..
Limestone and marly shale, *Clarksburg*	4	0	..	..
Sandstone, local, *Morgantown*	30	0	34	1
Coal, usually wanting, *Elk Lick*	..	1	..	..
Limestone and marly shale, *Elk Lick*	5	0	..	..
Shale, variable	5	0	..	..
Shale, siliceous, *Birmingham*	10	0	20	5
Limestone, local, marine, *Skelley*	..	4	..	..
Coal, seldom evident, *Duquesne*	..	1	..	..
Shale, variable	9	0	..	..
Shale, siliceous	11	0	..	..
Limestone, siliceous, marine, *Gaysport*	1	0	..	..
Shale, siliceous	16	0	54	6
Limestone, marine, *Ames*	1	6	..	..
Shale, siliceous	15	0	..	..
Coal, persistent, *Harlem*	1	0	..	..
Clay, calcareous	3	0	..	..
Clay shale, red, *Round Knob—(Pittsburgh)*	12	0	..	..
Sandstone, local, *Saltzburg*	8	0	26	0
Shale, siliceous	2	0	..	..
Coal, local, *Barton*	1	0	..	..
Clay shale	4	0	..	..
Limestone, ferruginous, *Ewing*	1	0	..	..
Shale, siliceous	3	0	..	..
Sandstone, local, *Cow Run*	15	4	29	0
Shale, siliceous	2	0	..	..
Limestone, marine, *Portersville*	2	0	..	..
Coal, persistent, *Anderson*	1	8	..	..
Clay shale	3	7	..	..
Limestone, local, *Bloomfield*	1	5	..	..
Shales, variable	19	0	30	0

	Thickness		Interval	
	Feet	*Inches*	*Feet*	*Inches*
Limestone, marine, *Cambridge*	4	0	..	..
Coal, unsteady, *Wilgus*	2	0	..	..
Clay shale	3	8	..	..
Shale or sandstone, *Buffalo*	23	0	..	..
Limestone, marine, *Brush Creek*	20	0	47	0
Coal, local, thin, *Brush Creek*	..	4	..	..
Shales, variable	10	6	11	0
Coal, local, *Mason*	..	6	..	..
Shale or sandstone, *Upper Mahoning*	10	0	11	0
Coal, *Mahoning, Groff*	1	0	..	..
Clay, irregular, *Thornton*	5	0	..	..
Limestone, local, *Mahoning*	2	0	32	0
Shale or sandstone, *Lower Mahoning*	25	0	..	..
Total	..	..	400	0
Allegheny Series				
Coal, patchy, *Upper Freeport No. 7*	3	0	..	..
Clay and shale	7	0	..	..
Limestone and marly shale, *Upper Freeport*	2	0	12	3
Coal, local, thin, *Bolivar*	..	3	..	..
Clay, flint and plastic, *Bolivar*	5	0	..	..
Shale or sandstone, *Upper Freeport*	33	0	39	0
Coal, patchy, *Lower Freeport, Rogers*	1	0	..	..
Clay, impure	2	6	..	..
Limestone, local, *Lower Freeport*	1	0	29	6
Shale or sandstone, *Lower Freeport*	25	0	..	..
Coal, seldom present, *Upper Kittanning*	1	0	..	..
Shale and sandstone	10	0	..	..
Shale, marine, *Washingtonville, (Yellow Kidney Ore)*	4	0	18	0
Coal, persistent, *Middle Kittanning No. 6*	4	0	..	..
Clay, siliceous	3	6	..	..
Limestone, impure, local, *Salem*	..	6	14	6
Shales, siliceous, with *Red Kidney Ore*	10	0	..	..
Coal, local, *Strasburg*	..	6	..	..
Clay, flint and plastic, *Oak Hill*	4	0	..	..
Shales, siliceous	3	0	13	4
Limestone, unsteady, marine, *Hamden*	4	0	..	..
Coal, *Lower Kittanning No. 5*	2	4	..	..

	Thickness Feet	Thickness Inches	Interval Feet	Interval Inches
Clay, plastic	5	0	5	4
Coal, shaly, local, *Lawrence*	..	4	..	..
Clay, flint and plastic	6	0	..	..
Shale and sandstone, *Kittanning*	8	2	..	..
Ore, irregular, *Ferriferous*	..	8	21	4
Limestone, marine, *Vanport*	6	0	..	..
Coal, seldom present, *Scrubgrass*	..	6	..	..
Shale, carbonaceous	5	0	9	0
Coal, patchy, *Clarion No. 4a*	4	0	..	..
Clay, flint and plastic	5	0	..	..
Ore, very local, *Canary*	..	6	17	0
Sandstone, irregular, *Clarion*	10	6	..	..
Coal, very local, *Winters*	1	0	..	..
Flint, impure, marine, *Zaleski*	1	0	2	0
Coal, local, *Ogan*	1	0	..	..
Shale and sandstone	25	0	..	..
Limestone, marine, *Putnam Hill*	4	0	31	0
Coal, steady, *Brookville No. 4*	2	0	..	..
Total	..	..	212	3
Pottsville Series				
Clay, plastic	4	0	..	..
Shale or sandstone, *Homewood*	10	0	15	0
Coal, local, *Tionesta No. 3b*	1	0	..	..
Clay, plastic	5	0	..	..
Shale and sandstone	24	0	..	..
Ore, irregular, *Upper Mercer, Big Red Block*	..	4	32	0
Limestone or flint, *Upper Mercer*	1	8	..	..
Coal, patchy, *Bedford*	1	0	..	..
Clay, siliceous	3	0	..	..
Shale and sandstone	7	0	..	..
Ore, siliceous, local, *Sand Block*	..	6	15	0
Shale and sandstone	3	6	..	..
Coal, local, *Upper Mercer No. 3a*	1	0	..	..
Clay, siliceous, plastic	3	0	..	..
Shale and sandstone	11	0	..	..
Ore, kidney, *Lower Mercer, Little Red Block*	..	3	..	..
Shale, siliceous	1	9	18	6

	Thickness		Interval	
	Feet	*Inches*	*Feet*	*Inches*
Limestone, steady, marine, *Lower Mercer*	2	0	..	..
Coal, steady, thin, *Middle Mercer*	..	6	..	..
Clay, siliceous, plastic	3	6	..	..
Shale and sandstone	5	0	9	0
Coal, thin, local, *Flint Ridge*	..	6	..	..
Clay, plastic and flint	4	0	..	..
Shale and sandstone	5	0	..	..
Ore and limestone, marine, *Boggs*	..	6	11	6
Shale, siliceous	1	0	..	..
Coal, steady, thin, *Lower Mercer No. 3*	1	0	..	..
Clay, siliceous	3	0	..	..
Shale and sandstone	23	0	28	0
Limestone or ore, marine, *Lowellville, Poverty Run*	1	0	..	..
Coal, thin, unsteady, *Vandusen*	1	0	..	..
Clay, impure	2	0	..	..
Shale and sandstone	17	0	20	6
Coal, local, *Bear Run*	1	6	..	..
Clay, siliceous	3	0	..	..
Shale or sandstone, *Connoquenessing* or *Massillon* (*Jackson Sand Block* and *Lincoln ores* in interval)	24	0	29	0
Coal, patchy, *Quakertown No. 2*	2	0	..	..
Clay, siliceous	5	0	..	..
Shale and sandstone	12	0	17	3
Coal, thin, local, *Huckleberry*	..	3	..	..
Clay, siliceous	3	0	..	..
Shale, argillaceous	1	0	..	..
Ore, local, *Guinea Fowl*	..	3	10	3
Shale, gray, siliceous	5	9	..	..
Coal, thin, *Anthony*	..	3	..	..
Clay, flint and plastic, *Sciotoville*	4	0	..	..
Shale and sandstone	20	0	..	..
Ore, local, marine, *Sharon*	..	3	32	0
Shale, siliceous	4	9	..	..
Coal, patchy, *Sharon No. 1*	3	0	..	..
Clay, impure	2	0	..	..
Shale, siliceous, irregular	5	0	18	0
Conglomerate, patchy, *Sharon*	10	0	..	..
Ore, local, impure, marine, *Harrison*	1	0	..	..
Total	..	..	256	0

PENNSYLVANIAN CYCLES IN WEST VIRGINIA

By David B. Reger[1]

INTRODUCTION

The Pennsylvanian or Upper Carboniferous system of rocks covers approximately 16,500 square miles of territory in central and northwestern West Virginia of which about 12,800 square miles outcrop at the surface and 3,700 square miles are covered by Permian beds. Its vast amount of commercial coal justifies careful study of all its phases. As shown by Figure 50 the

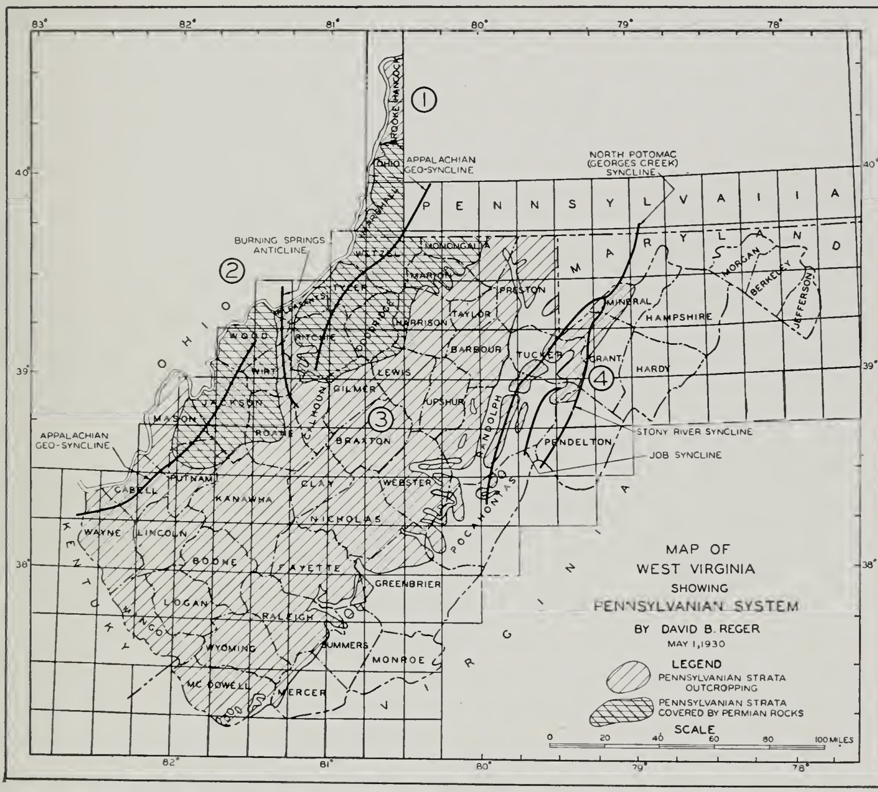


Fig. 50.

outcrops are as follows: (1), in the counties of the northern pan-handle northwest of the Appalachian geosyncline; (2), on either side of the Burning Springs anticline which cuts north and south across the geosyncline and

[1] Associate Geologist, West Virginia Geological Survey.

laterally displaces the axis of this basin; (3), in a broad central belt extending southwestward across the State from the Pennsylvania and Maryland lines to Kentucky and Virginia; (4), in the north Potomac (Georges Creek) syncline and certain of its branches extending from the Maryland state-line near Piedmont southwestward into Pocahontas and Pendeleton counties. Its position in the standard rock column of the State is illustrated by the following table:

Table 11.—*Partial geologic column of West Virginia*

Era	System	Series	Group
Paleozoic	Permian	Dunkard	Greene
			Washington
	Pennsylvanian	*Monongahela*	....
		Conemaugh	....
		Allegheny	....
		Pottsville	*Kanawha*
			New River
			Pocahontas
	Mississippian	Mauch Chunk	Bluestone
			Princeton
			Hinton
			Bluefield
		Greenbrier	....
		Maccrady	....
		Pocono	Pinkerton
			Myers
			Hedges
			Purslane
			Rockwell

GENERAL ASPECTS

In general the Pennsylvanian beds in West Virginia are composed of sandstones, limestones, fireclays, fireclay shales or sandy and carbonaceous shales, red and variegated shales, and coals.

The sandstones are of great variety, some being massive and quartzitic, either with or without large pebbles, whereas others are fine-grained and flaggy or shaly. Colors vary from white to greenish-gray or brown with a general tendency toward a final buff or light brown when fully weathered. Red sandstones are almost, if not entirely, unknown. In the Pottsville and Allegheny sandstones most of the ledges are coarse, massive, and often conglomeratic with a matrix of small quartz granules cemented by dissolved silica or iron peroxide. Conglomerate pebbles, when present, are invariably angular or rounded by rolling friction but never flattened and seldom elongated.

White quartz predominates but red jasper is not uncommon and darker silicates are also in evidence.

The limestones are partly marine and partly of fresh or brackish-water origin, and the two types differ materially in physical composition and appearance. The marine members, as a rule, are hard, siliceous, ferruginous and often carbonaceous and concretionary whereas the fresh-water beds are usually free from iron, are softer and more shaly, with a considerable proportion of argillaceous matter, and are much more uniformly bedded. These fresh-water beds occur principally in the upper Conemaugh and Monongahela series but are not unknown in the Allegheny. Most of the scanty Pottsville limestones are marine and probably all will be so classified when fully studied. The fresh-water beds usually contain ostracods and annelids with occasional fish teeth. In the Pottsville series the calcareous matter occurs frequently as large concretions, usually in the shales but not infrequently in the sandstones. Many of these larger concretions, especially in the shales, are jointed with regular rectangular seams of calcite, being familiarly known as turtle-backs.

The fireclays and fireclay shales are almost invariably the underclays of coals. The fireclay shales extend throughout the State but fireclays proper exist only in a restricted area of northern West Virginia next to Pennsylvania and Maryland and are largely confined to the Allegheny and Pottsville series.

Sandy and carbonaceous shales are common above many of the coals, being generally fissile or laminated and not infrequently containing marine or brackish-water fauna, as well as abundant plant fossils.

Red and variegated shales are confined to the Conemaugh and Monongahela series, the earliest Pennsylvanian red bed (Mahoning) being slightly above the Mahoning coal. Generally these red shales are streaked with green and yellow, have an irregular slickensided or brecciated structure, and are usually devoid of plant and animal remains.

The coals are of great variety and are susceptible of many classifications. Most of the older Pottsville beds, both in northern and southern West Virginia, are soft and fairly low in volatile matter but the younger Pottsville (Kanawha) coals, largely confied to southern areas, are high volatile and often splinty. In the Allegheny series there is a marked transition from soft to splint coals in passing southward. In the Conemaugh and Monongahela coals no splints occur. Cannel coals may be found at certain localities in the upper half of the Pottsville and in the Allegheny and Conemaugh series.

The clastic members of these Pennsylvanian beds were without doubt derived from the disintegration of ancient Applachia, a highland formerly existing along or west of the present Atlantic coast line. Carried westward by floods, the muds and sands were deposited in the Appalachian sea, a vast inland embayment which at certain periods reached from the Gulf region to

Canada. In various stages the marginal portion of this sea, covering the territory which is now West Virginia, was distinctly marine but in others there were evidently lagoons in which the water was fresh or slightly brackish. In still others the region was a huge swamp where carboniferous plants grew in abundance and were preserved as peat which later became coal.

The diastrophic flexures of the ground, which were of frequent occurrence, account for the alternating levels of the water and hence for the change from salinity to fresh-water and swampy conditions, with the consequent variation of sediments.

GENERAL STRATIGRAPHIC SECTION

Intelligent discussion of stratigraphic deposition may be facilitated by a study of the composite, or general, sections of the various series for the State and hence they are presented herewith starting with the Pottsville, or oldest series, and ending with the Monongahela or youngest. These sections were compiled mainly by Ray V. Hennen[2] and the writer[3] and have been previously published in County Reports of the West Virginia Geological Survey. The present versions, however, omit local details that have no general interest, and include certain corrections and additions for which the writer takes full responsibility. Instead of indicating maximum and minimum conditions the thickness column is revised to show the character of each sub-stage or formation in the locality where it is best developed; but in order to avoid expansion of the column beyond any known maximum in the State the thicknesses of certain variable beds have been purposely decreased.

[2] Hennen, Ray V., Fayette Report, West Virginia Geol. Survey, pp. 100-111 and 925-928, 1919; Monongalia-Marion-Taylor Report, p. 216, 1913; Braxton and Clay Report, pp. 228-229, 1917.

[3] Reger, David B., Lewis and Gilmer Report, p. 112, 1916; Mineral and Grant Report, pp. 203-205, 1924; Tucker Report, pp. 198-199, 1923.

TABLE 12.—*Generalized section of the Pottsville series of West Virginia*

(Arranged in descending stratigraphic order and showing the best known development of each sub-stage or formation)

	Thickness *Feet*	Total *Feet*
Kanawha group (2100 feet):		
Sandstone, Homewood, gray, massive, conglomeratic in northern W. Va.	95	95
Coal, Stockton "A" (Upper Mercer of Pa.), multiple-bedded, splinty, slaty	0 to 5	100
Kanawha Black Flint (Mercer Limestone of Pa.), bluish-black and cherty with marine fossils in portions of great Kanawha Valley; elsewhere mostly black shale	15 to 10	110
Coal, Stockton, (Lower Mercer of Pa.), multiple-bedded, splinty, mined extensively in the Kanawha Valley	0 to 10	120
Shale, sandy, with impure fireclays	60 to 50	170

	Thickness Feet	Total Feet
Sandstone, Upper Coalburg, (Upper Connoquenessing of Pa.), gray, coarse, massive, conglomeratic in northern W. Va....	80	250
Coal, Coalburg "A"....	1 to 0	250
Shale, Coalburg, with marine fossils....	11 to 10	260
Coal. Coalburg, (Quakertown, "Rider"), multiple-bedded, splinty layers, mined extensively in Kanawha Valley and in Mingo County	2 to 10	270
Black slate, Quakertown (supposed positon), brackish-water fossils	28 to 20	290
Coal, Little Coalburg, splinty, not mined commercially in State	0 to 3	293
Fireclay, impure, and sandy shale, with thin *coals*....	25 to 22	315
Sandstone, Lower Coalburg, gray, massive....	30 to 40	355
Shale, sandy	19 to 9	364
Coal, Buffalo Creek, multiple-bedded, hard, mined commercially in Mingo County....	0 to 6	370
Fireclay and shale....	63 to 55	425
Limestone, Buffalo Creek, hard, gray, lenticular, with marine fossils on Island Creek, Logan County, and at Rawl, Mingo County	0 to 2	427
Sandstone, Upper Winifrede, yellowish-gray, massive....	20 to 30	457
Shale	13 to 3	460
Coal, Winifrede (Quakertown? of Pa.), multiple-bedded, hard, splinty, mined extensively in Kanawha Valley....	1 to 10	470
Fireclay, impure, and sandy shale....	31 to 20	490
Coal, Lower Winifrede, multiple-bedded, splinty....	0 to 2	492
Sandstone, Lower Winifrede, gray, massive....	20 to 23	515
Shale	7 to 2	517
Coal, Chilton "A", multiple-bedded, not mined commercially in State	0 to 3	520
Fireclay, impure, and shale, (probable horizon of marine fossiliferous *Winifrede Limestone* of Winifrede Creek, Kanawha County, and Indian Gap, Raleigh County)....	21 to 18	538
Sandstone, Upper Chilton, gray, massive, medium-grained, micaceous	40	578
Coal, Chilton "Rider", splinty, multiple-bedded....	0 to 4	582
Fireclay shale	24 to 20	602
Coal, Chilton (Fireclay Coal of Ky.), multiple-bedded, splinty, mined extensively in Logan County....	1 to 8	610
Fireclay, impure, and shale....	13 to 5	615
Sandstone, Lower Chilton, massive....	25 to 30	645
Shale, sandy	5 to 0	645
Coal, Little Chilton, double-bedded....	0 to 2	647
Fireclay, shale, gray, sandy....	7 to 5	652
Sandstone, Hernshaw, gray, massive....	30 to 44	696
Shale, sandy or carbonaceous....	14 to 0	696
Coal, Hernshaw, multiple-bedded, mined in Kanawha County..	0 to 4	700
Fireclay and sandy shales....	14 to 10	710
Sandstone, Williamson	30	740

	Thickness Feet	Total Feet
Shale and Limestone, Dingess, gray and hard, frequently brown and siliceous, lenticular and ferriferous, with marine fossils, widely persistent in Kanawha, Fayette, Nicholas, Boone, Logan and Mingo counties	30	770
Sandstone, Dingess, lenticular	0 to 17	787
Shale	22 to 5	792
Coal, Williamson, multiple-bedded, splinty, mined commercially at Williamson and Dingess, Mingo County	1 to 8	800
Fireclay, impure, and shale	5	805
Sandstone, Upper Cedar Grove, gray, massive	30 to 40	845
Shales, dark-gray, with iron ore nodules and holding marine fossiliferous *Seth Limestone* of Boone County near base	60 to 50	895
Coal, Cedar Grove, multiple-bedded, splinty; when normal, the base of upper bench is hard and splinty; and reverse is true of lower bench; mined extensively in Kanawha Valley and Mingo County	2 to 5	900
Fireclay and shale	13 to 10	910
Sandstone, Middle Cedar Grove, gray, massive, frequently holding a thin coal	50 to 60	970
Shale, sandy	10 to 0	970
Coal, Lower Cedar Grove, multiple-bedded, splinty at top, mined commercially in Mingo County	2 to 5	975
Fireclay, impure, and shale	13 to 10	985
Sandstone, Peerless (same as *Lower Cedar Grove* of certain reports), gray, massive	30	1015
Coal, Alma "A", not mined commercially in State	0 to 1	1016
Shale, dark-gray, with iron ore nodules and plant fossils	10 to 9	1025
Coal, Alma, multiple-bedded, splinty layers, mined extensively in Logan, Mingo, and Boone counties	2 to 5	1030
Fireclay, impure, and shale	8 to 5	1035
Sandstone, Monitor, bluish-gray, massive, medium-grained, micaceous	30 to 40	1075
Shale, sandy	15 to 5	1080
Coal, Little Alma, multiple-bedded, slaty, not mined commercially in State	0 to 3	1083
Fireclay, shale, sandy	3 to 0	1083
Sandstone, Lower Monitor, gray, massive, micaceous	20 to 29	1112
Shale, gray, sandy, and flaggy	14 to 5	1117
Limestone, Campbell Creek, dark-gray, hard, siliceous, lenticular	0 to 2	1119
Shales, flaggy and sandy, with iron ore nodules and plant fossils	22 to 20	1139
Coal, Campbell Creek, multiple-bedded, gas type, includes both the *Peerless* and *No. 2 Gas* seams in Kanawha Valley, and *Warfield, Freeburn, Burnwell,* and *Upper War Eagle* beds of Mingo County, mined commercially over wide area in southern half of State	2 to 6	1145
Shale, sandy	4 to 0	1145

	Thickness *Feet*	Total *Feet*
Sandstone, Lower Campbell Creek	30	1175
Coal, Lower Campbell Creek, multiple-bedded, not mined commercially in State	0 to 4	1179
Shale, sandy	4 to 0	1179
Sandstone, Brownstown, bluish-gray and brown, massive, micaceous	17	1196
Coal, Powellton "A", double-bedded, not mined commercially in State	0 to 1	1197
Shale, sandy, flaggy, laminated	19 to 18	1215
Coal, Powellton, multiple-bedded, both gas and splinty type, mined extensively in Fayette County	0 to 5	1220
Shale, dark, laminated	25 to 20	1240
Limestone, Stockton, "Cannelton", siliceous, lenticular, carrying marine fossils on Simmons Creek, Kanawha County	0 to 4	1244
Shales, dark, with marine fossils in southeastern Boone and northern Wyoming counties	38 to 34	1278
Coal, Matewan, double-bedded, soft gas type, not mined commercially in State	0 to 5	1283
Shale, sandy	5 to 0	1283
Sandstone, Matewan, gray, massive	37	1320
Coal, Eagle "A", soft gas type, not mined commercially in State	0 to 2	1322
Shale, sandy	2 to 0	1322
Sandstone, Eagle, gray and brown, massive, coarse	30 to 37	1359
Shale, Newlon, dark, fissile, with marine fossils in southern W. Va.	17 to 10	1369
Coal, Eagle, both soft, gas and semi-splint type, multiple-bedded, mined extensively in Fayette, Mingo, and McDowell counties	1 to 6	1375
Fireclay, impure, and shale	10 to 5	1380
Sandstone, Bens Creek	27	1407
Coal, Bens Creek, multiple-bedded, soft, gas, columnar type, and apparently a split off the Eagle bed proper of Fayette County	0 to 3	1410
Fireclay and shale	13 to 10	1420
Sandstone, Decota, gray, massive	40 to 57	1477
Shale, carrying marine fossils at Oceana and northwest of Elklick, Wyoming County, and brackish-water fossil fauna at Smithers, Fayette	26 to 9	1486
Coal, Little Eagle, multiple-bedded, soft, gas, columnar type, once mined commercially near Parral, Fayette County	1 to 4	1490
Shale, sandy	3 to 0	1490
Sandstone, flaggy and shaly	20	1510
Coal, Cedar, multiple-bedded, soft, gas type, once mined commercially at Cedar, Mingo County	0 to 4	1514
Shale, sandy	4 to 0	1514
Sandstone, Grapevine, gray, massive	25 to 30	1544
Shale, Eagle, (upper bench), dark to black, laminated, with marine fossils	25 to 20	1564

	Thickness *Feet*	Total *Feet*
Limestone, Eagle, dark, brittle, lenticular, with marine fossils widely persistent from Kanawha River to Kentucky and Virginia line	0 to 2	1566
Shale, Eagle (lower bench), black, with iron ore nodules and marine fossils	27 to 25	1591
Coal, Little Cedar, not mined commercially in State	0 to 1	1592
Sandstone, Lower War Eagle, flaggy, micaceous	20 to 30	1622
Shale, black, with plant fossils	20 to 10	1632
Coal, Lower War Eagle, multiple-bedded, soft, gas type, not mined commercially in State	0 to 3	1635
Shale	8 to 5	1640
Sandstone, Upper Gilbert, grayish, massive, medium-grained	40 to 50	1690
Shale, black, laminated, siliceous, with iron ore nodules, at Oceana, carrying the dark-gray, siliceous, lenticular *Oceana Limestone* (0" to 24") near top	25 to 15	1705
Sandstone, bluish-gray to dark, laminated	15	1720
Coal, Glenalum Tunnel, multiple-bedded, soft, gas, columnar type, much split up with slate partings 1 to 2 feet thick, not mined commercially in State	0 to 15	1735
Shale, sandy	15 to 0	1735
Sandstone, Lower Gilbert, grayish-white to brown, massive	50 to 79	1814
Coal, Gilbert "A", multiple-bedded, soft, gas, columnar type, observed only in southwest edge of McDowell County	0 to 1	1815
Shale, Gilbert, dark, flaggy, laminated, with marine fossils in various southern counties	35 to 5	1820
Coal, Gilbert, multiple-bedded, soft, gas, columnar type, important seam in western Wyoming County and in Fayette and Nicholas counties	0 to 4	1824
Shale, sandy, lenticular	10 to 6	1830
Sandstone, Dotson (same as *Bearwallow Conglomerate* of Tazewell Folio U. S. Geological Survey), current-bedded, medium-grained to coarse, frequently pebbly	75 to 125	1955
Coal, Douglas, "A", observed only in southern McDowell	1 to 0	1955
Shale, sandy, lenticular	59 to 10	1965
Coal, Douglas, generally single-bedded, soft, columnar type, mined commercially at Douglas Station, McDowell County.	1 to 5	1970
Fireclay, shale, sandy	9 to 5	1975
Sandstone, Lower Dotson, grayish-white to brown, heavy to current-bedded, sometimes conglomeratic, friable	50 to 100	2075
Shale, Douglas, dark, sandy, laminated, with marine or brackish-water fossil fauna at base	65 to 15	2090
Coal, Lower Douglas, multiple-bedded, soft, gas, columnar type, not mined commercially in State	1 to 5	2095
Shale, gray and sandy	9 to 5	2100
New River Group (1030 feet):		
Sandstone, Upper Nuttall, grayish white to brown, massive to heavy and current-bedded, conglomeratic in many localities.	50	2150

	Thickness Feet	Total Feet
Shale, dark, sandy	0 to 7	2157
Coal, Iaeger "B", multiple-bedded, soft, gas, columnar type, not mined commercially	0 to 3	2160
Shale, sandy	10 to 0	2160
Sandstone, Lower Nuttall, "Upper Iaeger", gray to brown, massive, medium-grained, often conglomeratic	80 to 50	2210
Coal, Iaeger "A", slaty and sulphurous, observed only on headwaters of Panther Creek, McDowell County	2 to 0	2210
Shale, Upper Iaeger, dark, argillaceous, laminated, with plant fossils at base	28 to 60	2270
Coal, Iaeger (Hughes Ferry), generally double-bedded; soft, columnar, mined locally at Iaeger, McDowell County	1 to 5	2275
Shale, sandy	9 to 5	2280
Sandstone, Middle Iaeger, grayish-white, massive, medium-grained to coarse	40	2320
Coal, Lower Iaeger, double-bedded, soft, columnar, not mined commercially in State	0 to 2	2322
Fireclay shale	5 to 3	2325
Sandstone, Lower Iaeger, gray and brown, massive, medium-grained, micaceous	20 to 30	2355
Shale, Lower Iaeger, dark-gray, argillaceous, laminated	45 to 35	2390
Sandstone, Harvey Conglomerate, grayish-white to brown, current-bedded to massive, conglomeratic, medium-grained to coarse	60 to 25	2415
Shale, Sandy Huff, dark-gray, argillaceous, laminated	5 to 40	2455
Coal, Castle, multiple-bedded, soft, columnar, irregular, not mined commercially	2 to 0	2455
Fireclay shale, sandy	0 to 2	2457
Sandstone, Guyandot, grayish-white, massive, current-bedded, often conglomeratic, medium-grained to coarse, lenticular	65 to 73	2530
Shale, Skelt, dark and sandy with marine fossils	13 to 5	2535
Coal, Sewell "B", multiple-bedded, soft, columnar, attains minable dimensions only in southeastern Wyoming and McDowell counties	0 to 5	2540
Shale, sandy, flaggy, laminated	29 to 24	2564
Coal, Sewell "A", double-bedded, soft, columnar, not mined commercially in State	0 to 1	2565
Sandstone, Lower Guyandot, grayish-white, massive to current-bedded, medium-grained, lenticular	30 to 50	2615
Shale, Hartridge, dark, fissile and ferruginous, with plant fossils and a fresh or brackish-water fauna	25 to 5	2620
Coal, Sewell (Sharon of Pa.) generally double-bedded, soft, columnar, mined commercially in many counties	0 to 10	2630
Shale, gray, sandy, lenticular, often carries many plant roots	15 to 5	2635
Sandstone, Welch, grayish-white, massive to current-bedded, lenticular	40 to 50	2685
Shale, dark, argillaceous, lenticular, with occasional brackish-water fauna	15 to 5	2690

	Thickness *Feet*	Total *Feet*
Coal, Welch, multiple-bedded, soft, columnar, mined commercially in a few southern counties	0 to 5	2695
Shale, gray, sandy	10 to 5	2700
Sandstone, Upper Raleigh (Sharon of Pa.), grayish-white to brown, heavy to current-bedded, generally conglomeratic in northern W. Va	85 to 75	2775
Coal, Little Raleigh "A", not mined commercially	0 to 3	2778
Shale, sandy, lenticular	18 to 25	2803
Coal, Little Raleigh, multiple-bedded, soft, columnar, not mined commercially in State	4 to 2	2805
Shale, sandy, lenticular	3 to 5	2810
Sandstone, Lower Raleigh, massive to current-bedded, lenticular	69 to 50	2860
Coal, Beckley "Rider"	0 to 2	2862
Shale, dark-gray, argillaceous, lenticular	0 to 17	2879
Coal, Beckley, multiple-bedded, soft, columnar, mined commercially in Raleigh and McDowell counties	0 to 10	2889
Fireclay shale, sandy	15 to 5	2894
Sandstone, Quinnimont, lenticular	50 to 61	2955
Shale, Quinnimont, dark-gray, siliceous to argillaceous, laminated, lenticular	46 to 35	2990
Coal, Fire Creek, "Quinnimont", multiple-bedded, soft, columnar, mined commercially in Fayette and Raleigh counties	0 to 5	2995
Shale, sandy, with sandstone layers	33 to 28	3023
Coal, Little Fire Creek, multiple-bedded, soft, columnar, not mined commercially in State	0 to 2	3025
Shale, sandy	2 to 0	3025
Sandstone, Pineville, gray, massive to current-bedded	50 to 65	3090
Shale, sandy	20 to 5	3095
Coal, No. 9 Pocahontas, multiple-bedded, soft, columnar, not mined commercially in State	0 to 5	3100
Shale and sandstone mixed	33 to 28	3128
Coal, No. 8 Pocahontas, impure, soft, columnar, not mined commercially in State	0 to 2	3130
Fireclay shale, sandy	2 to 0	3130
Pocahontas Group (720 feet):		
Sandstone, Flattop Mountain, bluish-gray, to brown, massive to current-bedded, medium-grained, micaceous	20 to 50	3180
Shale, Rift, dark-gray, with argillaceous and siliceous layers	47 to 17	3197
Coal, No. 7 Pocahontas, multiple-bedded, soft, columnar, not mined commercially in State	0 to 3	3200
Shale, gray and sandy	8 to 5	3205
Sandstone, Pierpont, bluish-gray to light-gray, heavy to current-bedded, medium-grained, hard, micaceous	40 to 60	3265
Shale, sandy, alternating with sandstone	55 to 35	3300
Shale, Royal, buff, sandy, with fresh or brackish-water fossil fauna in Raleigh, Fayette and Mercer counties	5	3305

	Thickness *Feet*	Total *Feet*
Coal, No. 6 Pocahontas, multiple-bedded, soft, columnar, mined commercially in Mercer County and just below Rainelle, Fayette County	0 to 5	3310
Shale, sandy	10 to 5	3315
Sandstone, Eckman, buff to bluish-gray, massive to current-bedded, medium-grained	50 to 67	3382
Shale, sandy	17 to 0	3382
Coal, No. 5 Pocahontas, multiple-bedded, soft, columnar, not mined commercially in State	0 to 5	3387
Shale, sandstone, and dark shale, with plant fossils abundant	25 to 20	3407
Coal, No. 4 Pocahontas, multiple-bedded, soft, columnar, mined commercially on Elkhorn Creek and Tug Fork, McDowell County	0 to 8	3415
Shale, sandy	13 to 5	3420
Sandstone, Upper Pocahontas, massive to heavy-bedded, medium-grained to coarse	40 to 55	3475
Coal, No. 3 Pocahontas "Rider", not mined in State	2 to 0	3475
Shale, dark, with plant fossils abundant, and fresh or brackish-water fossil fauna reported on Piney Creek, Raleigh County	23 to 10	3485
Coal, No. 3 Pocahontas, multiple-bedded, soft, columnar, mined extensively in McDowell, Mercer, and Wyoming counties	0 to 15	3500
Shale, gray and sandy	25 to 10	3510
Sandstone, Lower Pocahontas, generally massive, medium-grained, when shaly often carries 18" to 24" of *slaty coal (No. 2 Pocahontas "A")* near middle	40 to 50	3560
Shale, gray and sandy	18 to 8	3568
Coal, No. 2 Pocahontas, multiple-bedded, soft, columnar, not mined commercially in State	0 to 2	3570
Shale, gray	7 to 5	3575
Sandstone, Vivian, bluish-gray, massive, medium-grained, lenticular	20 to 29	3604
Coal No. 1 Pocahontas, generally single-bedded, soft, columnar, not mined in State	0 to 1	3605
Shale, sandy	10 to 0	3605
Sandstone, Landgraff, buff, massive, medium-grained, micaceous	15 to 20	3625
Shale, sandy	6 to 0	3625
Coal, Landgraff, soft, columnar, not mined in State	0 to 1	3626
Sandstone, Keystone, buff, massive, medium-grained, micaceous	20 to 23	3649
Coal, Keystone, impure, not mined in State	0 to 1	3650
Shale and sandstone	19 to 15	3665
Shale, North Fork, black, fissile, with thin lenses (1" to 2") of iron ore, carrying fresh or brackish-water fossil fauna	10	3675
Coal, Simmons, soft, columnar	0 to 1	3676
Shale and sandstones, alternating	123 to 122	3798
Coal, Squire Jim, multiple-bedded, soft, columnar, observed only near Squire Jim, McDowell County	0 to 2	3800
Shale and sandstone to top of *Mississippian,* or red shales of *Mauch Chunk*	52 to 50	3850

TABLE 13.—*Generalized section of the Allegheny series for West Virginia*
(Arranged in descending stratigraphic order and showing best known development of each sub-stage or formation)

	Thickness Feet	Total Feet
Coal, Upper Freeport, multiple-bedded	0 to 5	5
Fireclay shale, Bolivar	10 to 5	10
Limestone, Upper Freeport, lenticular, fresh-water, frequently replaced with iron ore	0 to 5	15
Shale, sandy	5 to 0	15
Sandstone, Upper Freeport, gray, massive, coarse, often conglomeratic, with large white and bluish-black quartz pebbles	50 to 63	78
Shale, sandy, or carbonaceous	18 to 5	83
Coal, Lower Freeport, irregular, lenticular	0 to 2	85
Fireclay shale and sandy shale; occasionally ferruginous	10 to 15	100
Limestone, Lower Freeport, fresh-water	7 to 0	100
Sandstone, Lower Freeport, gray, massive, coarse	45	145
Coal, Upper Kittanning "Rider", a split off the *Upper Kittanning* proper	3 to 0	145
Shale, sandy or carbonaceous	18 to 15	160
Coal, Upper Kittanning, multiple-bedded	2 to 5	165
Fireclay, Upper Kittanning	10 to 5	170
Limestone, Johnstown, gray, fresh-water	0 to 5	175
Fireclay, Hardman	13 to 10	185
Sandstone, Upper East Lynn, gray, massive, often conglomeratic with large quartz pebbles	30 to 57	242
Shale, sandy or carbonaceous	27 to 0	242
Coal, Middle Kittanning, multiple-bedded	0 to 8	250
Fireclay, shale, sandy	13 to 5	255
Sandstone, East Lynn, massive	25 to 62	317
Shale, sandy or carbonaceous, rarely marine	37 to 0	317
Coal, Lower Kittanning, "No. 5 Block", multiple-bedded	4 to 8	325
Fireclay, Lower Kittanning	9 to 0	325
Limestone, Vanport, ferruginous, often carries marine fauna in Ohio and Pa., but seldom in W. Va	0 to 5	330
Sandstone, Kittanning	10 to 15	345
Shale, sandy or carbonaceous	5 to 0	345
Coal, Clarion	5 to 0	345
Fireclay, Clarion	0 to 5	350
Sandstone, Homewood, upper member of Pottsville	.. ..	....

TABLE 14.—*Generalized section of the Conemaugh series for West Virginia*
(Arranged in descending stratigraphic order and showing best known development of each sub-stage or formation)

Coal, Pittsburgh, basal member of Monongahela series	.. ..	....
Fireclay and shale	5	5
Limestone, Fairfax, lenticular, fresh-water origin	0 to 2	7
Shale	10 to 8	15
Coal, Morantown, lenticular, and impure, multiple-bedded	1 to 5	20
Shale	39 to 35	55

	Thickness Feet	Total Feet
Sandstone, Lower Pittsburgh, shaly	5 to 10	65
Shale, dark	9 to 4	69
Limestone, Upper Pittsburgh, gray, fresh-water	5 to 0	69
Coal, Little Pittsburgh, multiple-bedded, lenticular	1 to 6	75
Shale, sandy	29 to 19	94
Limestone, Lower Pittsburgh, gray, fresh-water	0 to 10	104
Coal, Second Little Pittsburgh, lenticular	0 to 1	105
Shale, sandy	5 to 4	109
Sandstone, Connellsville, brown, massive	20	129
Coal, Franklin "Rider", lenticular	0 to 1	130
Shale, sandy	13	143
Coal, Little Clarksburg, "Franklin", "Dirty Nine-foot", multiple-bedded, impure	2 to 7	150
Fireclay shale, Clarksburg, gray	10 to 5	155
Shale, sandy, upper bench of *Clarksburg Red Shale*	19	174
Sandstone, Lower Connellsville (Hoffman of Maryland Survey?), massive, brown	25	199
Coal, Normantown, (Upper Hoffman of Maryland Survey?)	0 to 1	200
Fireclay shale	5 to 0	200
Limestone, Clarskburg, gray, fresh-water	15 to 0	200
Shale, sandy, middle bench of *Clarksburg Red Shale*	5 to 24	224
Coal, Lower Hoffman, lenticular	0 to 1	225
Shale, sandy	10 to 9	234
Coal, Upper Clarysville, lenticular	0 to 1	235
Shale, sandy	16 to 14	249
Coal, Lower Clarysville, lenticular	0 to 1	250
Shale, variegated and sandy, contains streak of limestone near Blaine, lower bench of *Clarksburg Red Shale*	40	290
Sandstone, Morgantown, gray, massive, medium-hard	24 to 20	310
Shale, dark, sandy	0 to 4	314
Coal, Wellersburg "Rider", lenticular	0 to 1	315
Shale	10 to 9	324
Coal, Wellersburg, lenticular	0 to 1	325
Shale	5 to 4	329
Coal, Barton "Rider", lenticular	0 to 1	330
Sandstone, Barton, shaly	13 to 10	340
Shale, dark	3 to 6	346
Limestone, Orlando, gray, fresh or brackish water fauna	3 to 0	346
Coal, Elk Lick, "Barton", "Four-foot", often double-bedded, and frequently bony at top and bottom	2 to 4	350
Fireclay shale	5 to 0	350
Limestone, Elk Lick, gray, fresh-water	5 to 0	350
Coal, West Milford	1 to 0	350
Shale, Birmingham (upper bench), red and variegated	30 to 39	389
Sandstone, Upper Grafton, massive, brown, medium-hard	10	399
Coal, Federal Hill, lenticular	0 to 1	400
Shale, Birmingham (middle bench), red and variegated	9	409
Coal, Duquesne, lenticular	0 to 1	410

	Thickness Feet	Total Feet
Shale Birmingham (lower bench), red and variegated...........	10	420
Sandstone, Grafton, massive, brown, hard.......................	20	440
Shale, Ames, dark-green, with marine fossils (lenticular, fossiliferous limestones known as *Upper and Lower Ames* frequently occur near top and bottom of shale)...............................	9 to 8	448
Coal, Harlem, soft, single-bedded..............................	1 to 2	450
Fireclay shale, yellow..	10 to 5	455
Limestone, Ewing, gray nodular, fresh-water....................	0 to 5	460
Shale, Pittsburgh (upper bench), red and variegated............	10	470
Sandstone, Jane Lew, massive or shaly.........................	15	485
Shale, Pittsburgh (lower bench), red and variegated............	20	505
Sandstone, Saltsburg, massive, gray or brown, sometimes pebbly...	30 to 40	545
Shale, dark, supposed horizon of marine *Portersville limestone of* Ohio	10 to 0	545
Coal, Upper Bakerstown, multiple-bedded.......................	1 to 5	550
Shale, dark, sandy and ferruginous.............................	29 to 25	575
Sandstone, Thomas, shaly or massive...........................	10 to 20	595
Shale, dark, sandy..	10 to 0	595
Coal, Bakerstown, "Thomas", multiple-bedded....................	3 to 5	600
Shale, sandy	7 to 5	605
Limestone, Albright, fresh or brackish-water origin, lenticular....	0 to 1	606
Shale, sandy or slightly red..................................	12	618
Limestone, Pine Creek (Cambridge of Ohio?), often represented by a sandy, ferruginous zone and carrying marine fossils, lenticular	0 to 2	620
Shale, Meyersdale, sandy or red and variegated.................	13 to 10	630
Sandstone, Buffalo, gray, massive, medium-hard and medium-coarse	20 to 35	665
Shale and limestone, Brush Creek, black, with marine fossils......	24 to 9	674
Coal, Brush Creek, lenticular.................................	0 to 1	675
Fireclay shale, Brush Creek..................................	23	698
Sandstone, Upper Mahoning, gray, massive, hard, coarse..........	40	738
Limestone, Sutton, fresh or brackish-water origin, lenticular......	0 to 1	739
Shale, Mahoning, red, lenticular..............................	0 to 5	744
Shale, dark	11 to 5	749
Coal, Mahoning, "Six-foot", multiple-bedded.....................	1 to 6	755
Fireclay, Thornton	15 to 10	765
Sandstone, Lower Mahoning, gray, massive, hard, coarse.........	25	790
Shale, Uffington, dark, sandy..................................	10	800
Coal, Upper Freeport, "Split-six", "Davis", upper member of Allegheny series	.. ..	....

TABLE 15.—*Generalized section of the Monongahela series for West Virginia*

(Arranged in descending stratigraphic order and showing best known development of each sub-stage or formation)

Coal, Waynesburg, multiple-bedded, with fossil cockroaches in partings	0 to 5	5
Shale, gray or red..	15 to 10	15
Sandstone, Gilboy, gray or green..............................	10 to 30	45
Shale, sandy	25 to 5	50

	Thickness Feet	Total Feet
Coal, Little Waynesburg	0 to 1	51
Limestone, Waynesburg, gray, fresh-water	0 to 4	55
Shale, gray or red	10 to 13	68
Sandstone, Uniontown, gray or green	20 to 35	103
Shale, Annabelle, brown	15 to 0	103
Coal, Uniontown, multiple-bedded	0 to 2	105
Shale, gray or red	0 to 10	115
Limestone, Uniontown, gray, fresh-water	0 to 15	130
Shale, red or green, with thin sandstones and limestones	59 to 44	174
Sandstone, Arnoldsburg, gray or green	30 to 25	199
Shale, sandy or carbonaceous	0 to 5	204
Coal, Lower Uniontown	0 to 1	205
Limestone, Arnoldsburg, yellow, fresh-water	5 to 0	205
Shale, Fulton, green	0 to 5	210
Limestone, Benwood, gray, fresh-water	5 to 65	275
Sandstone, Sewickley, gray	10 to 25	300
Shale, sandy or carbonaceous	15 to 0	300
Coal, Sewickley	0 to 5	305
Fireclay shale	10 to 5	310
Sandstone, Lower Sewickley, gray	10 to 20	330
Shale, sandy or carbonaceous	10 to 0	330
Coal, Lower Sewickley	2 to 0	330
Limestone, Sewickley, gray or yellow, fresh-water	0 to 33	363
Sandstone, Cedarville, gray or green	40 to 10	373
Shale, sandy or carbonaceous	5 to 0	373
Coal, Redstone	0 to 4	377
Fireclay shale	2 to 0	377
Sandstone, Weston, gray or green	20 to 0	377
Limestone, Redstone, yellow, fresh-water	0 to 5	382
Sandstone, Upper Pittsburgh, gray	0 to 15	397
Shale, Weston, gray	10 to 5	402
Coal, Pittsburgh	0 to 8	410

VARIATIONS IN THICKNESS

In all four series there are regional variations in thickness, due partly to changes within members and partly to the presence of new members in regions of maximum thickness. This variation is extreme in the Pottsville series whose thickness along the Pennsylvania and West Virginia state-line is only about 300 feet where the section is composed of a few members of the Kanawha and New River groups. It thickens southward to 3850 feet near the extreme southern end of West Virginia, accounted for partly by the development of the Pocahontas group and partly by additions to the Kanawha and New River groups.

The thickness of the Allegheny series in the North Potomac syncline near Maryland is only 175 feet but it increases southwestward and becomes

350 feet in Clay County. The Conemaugh series has a minimum of 450 feet in the northern pan-handle and increases southeastward to 800 feet near Piedmont, Mineral County. The Monongahela series is only 250 feet thick in the northern pan-handle but expands southeastward to 410 feet in Monongalia, Marion and other counties of the Monongahela Valley. The total thickness of the Pennsylvanian system does not occur at any single locality but is known to approximate 5410 feet.

CYCLES OF DEPOSITION

In a most admirable paper of the present year (1930) Dr. J. Marvin Weller[4] has recently called attention to the rather dormant theory of cyclical sedimentation in the Pennsylvanian system of the central states, particularly in Illinois and Ohio, reviewing also the earlier generalization of Udden[5] with respect to this system in Illinois, as published in 1912. Early in 1929 the writer,[6] in a public address before the West Virginia Academy of Science, made the following statement relative to the Monongahela series:

> "The Monongahela series is composed of sandstones, limestones, shales and coals. In general a limestone bed is followed above by fireclay shale, then by coal, then by sandy shale, with a covering of sandstone. Above the sandstone there may be a brief interval of shale before the next stratigraphic cycle begins. Assuming that each sandstone represents the definite termination of a stratigraphic sub-stage or depositional cycle it is evident that there have been nine such cycles in the history of Monongahela deposition and at the top a tenth is completed by the Waynesburg sandstone of Permian age. Certain of these stages lack the presence of a distinct coal and in certain others there is an absence of limestone, either regional or local."

The idea as above expressed illustrates the remarkable harmony of conclusions that may be reached by different geologists working on similar sediments in widely separated areas.

In the elaboration of his subject Dr. Weller now proposes that each cyclical repetition of beds be considered a formation of the Pennsylvanian system and further suggests that as the principal unconformity exists at the base of each sandstone this horizon should be taken as the beginning of a formation. It is most interesting to relate that in the discussion of the writer's paper before the West Virginia Academy, Mr. Wilbur Stout of Ohio made a similar suggestion to which the writer agreed in principle although recognizing the practical difficulty that would most certainly occur in attempting to revise the vast amount of geologic literature already published on the Appalachian coal basin.

---

[4] Weller, J. Marvin, Cyclical Sedimentation of the Pennsylvanian Period and its Significance, Journal of Geology vol. 38, pp. 97-135; Feb.-March, 1930.

[5] Udden, J. A., Geology and Mineral Resources of the Peoria Quadrangle, U. S. Geol. Survey, Bull. 506, pp. 47-50; 1912.

[6] Reger, David B., The Monongahela Series of West Virginia, Proc. W. Va. Acad. Sci. vol. 3, pp. 134-146, Aug., 1929.

In Udden's grouping of the beds of the Peoria quadrangle each formation starts with the base of a coal and extends to the top of the next underclay. In Weller's interpretation of this column a formation starts with the base of a sandstone and ends with the sandy or calcareous shales which overlie the next coal. The division of the writer calls for a sub-stage or formation starting at the top of a sandstone or the base of the succeeding shale and extending to the top of the next sandstone.

On theoretical grounds with respect to unconformities and arrested deposition, Dr. Weller's conclusion is doubtless well taken although it is safe to say that irregularity of bedding at the base of a sandstone often does not represent unconformity but merely a previous irregular surface. On practical grounds, however, the fact that early students of Appalachian geology, like the Rogers brothers, Stevenson, and I. C. White, almost invariably attached the same proper name to a coal and its overlying sandstone and underlying or overlying shales and limestones has created a vast number of fixed names which cannot easily be rejected. Also it is certain that structural and areal mapping can be much more easily executed if the top, rather than the base, of a sandstone be used. In the Appalachian basin, for instance, no geologist would think of using the bottom of the Homewood sandstone for a plane of reference but on the contrary its top has often been employed with good results. The writer therefore prefers to regard the top of a sandstone as the proper division plane.

On this basis the Pennsylvanian system of West Virginia may be divided into sub-stages or formations as shown by Figures 51 and 52.

In Figures 51 and 52 it is apparent that the maximum succession of beds in each sub-stage or cycle is as follows:

9. Sandstone.
8. "A" coal, or "Rider" coal (Ridercoal).
7. Ferruginous or sandy shale (Overshale B).
6. Ferruginous or sandy limestone, with or without marine fossils (Overlimestone).
5. Black fissile shale with plant fossils or a brackish-water fauna (Overshale A).
4. Principal coal.
3. Fireclay or fireclay shale (Undershale B).
2. Fresh-water limestone (Underlimestone).
1. Sandy or red and variegated shale (Undershale A).

In the Pottsville series there are evidently 58 cycles; in the Allegheny 5; in the Conemaugh 18; and in the Monongahela 10; making a total of 91 for the Pennsylvanian of West Virginia, with a possibility that two or three more may be finally differentiated near the base of the Pottsville and perhaps a few others in the younger series.

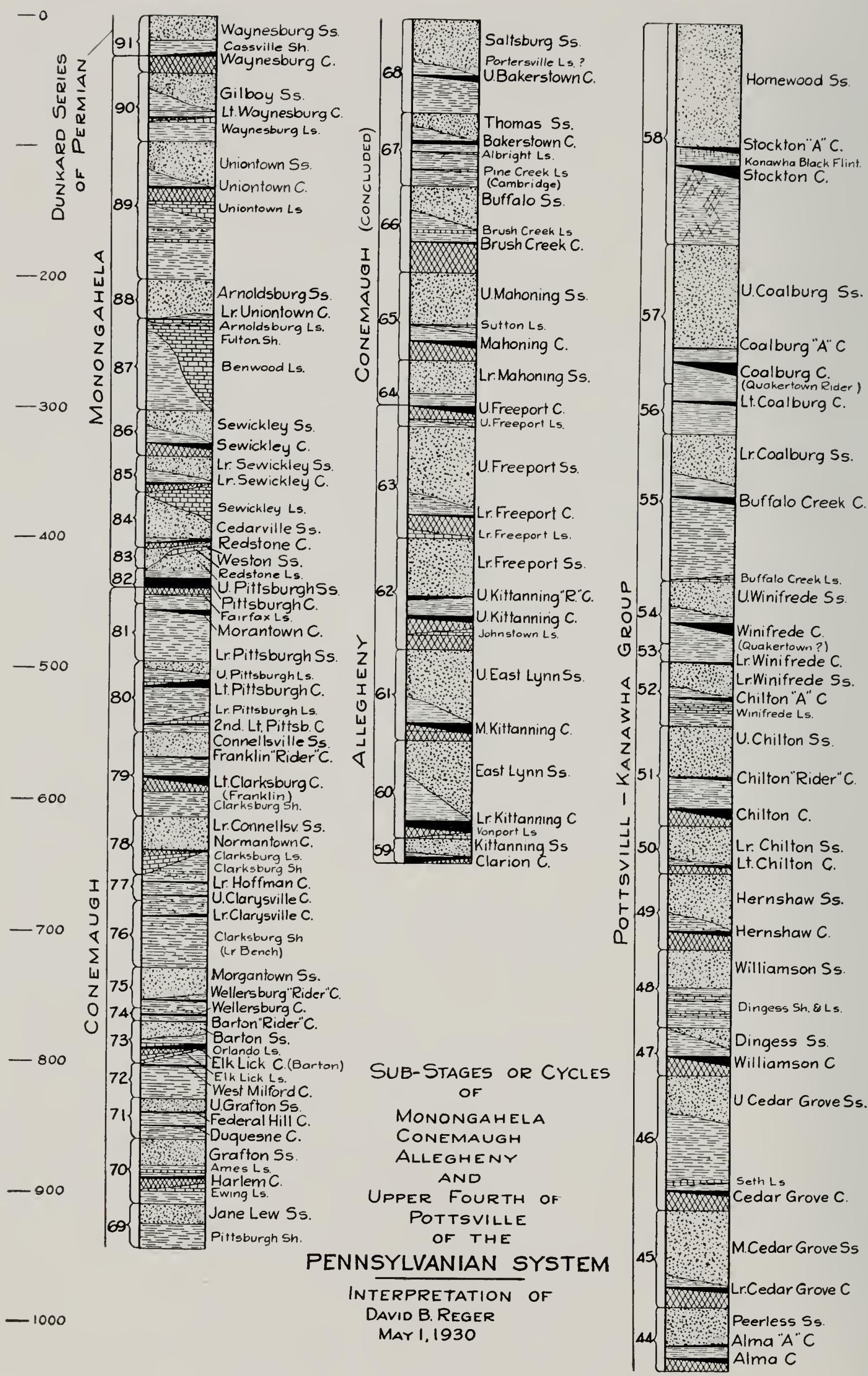

0
200
300
400
500
600
700
800
900
1000
Dunkard Series of Permian
Monongahela
Conemaugh
91 Waynesburg Ss.
Cassville Sh.
Waynesburg C.
90 Gilboy Ss.
Lt. Waynesburg C.
Waynesburg Ls.
Uniontown Ss.
Uniontown C.
89 Uniontown Ls
88 Arnoldsburg Ss.
Lr. Uniontown C.
Arnoldsburg Ls.
Fulton Sh.
87 Benwood Ls.
86 Sewickley Ss.
Sewickley C.
85 Lr. Sewickley Ss.
Lr. Sewickley C.
Sewickley Ls.
84 Cedarville Ss.
Redstone C.
83 Weston Ss.
Redstone Ls.
82 U. Pittsburgh Ss.
Pittsburgh C.
Fairfax Ls.
81 Morantown C.
Lr. Pittsburgh Ss.
U. Pittsburgh Ls.
Lt. Pittsburgh C.
80 Lr. Pittsburgh Ls.
2nd. Lt. Pittsb. C
Connellsville Ss.
Franklin "Rider" C.
79 Lt. Clarksburg C.
(Franklin)
Clarksburg Sh.
Lr. Connellsv. Ss.
78 Normantown C.
Clarksburg Ls.
Clarksburg Sh
77 Lr. Hoffman C.
U. Clarysville C.
Lr. Clarysville C.
76 Clarksburg Sh
(Lr Bench)
75 Morgantown Ss.
Wellersburg "Rider" C.
74 Wellersburg C.
Barton "Rider" C.
73 Barton Ss.
Orlando Ls.
Elk Lick C. (Barton)
72 Elk Lick Ls.
West Milford C.
U. Grafton Ss.
71 Federal Hill C.
Duquesne C.
Grafton Ss.
70 Ames Ls.
Harlem C.
Ewing Ls.
69 Jane Lew Ss.
Pittsburgh Sh.
Conemaugh (Concluded)
Allegheny
68 Saltsburg Ss.
Portersville Ls. ?
U. Bakerstown C.
67 Thomas Ss.
Bakerstown C.
Albright Ls.
Pine Creek Ls
(Cambridge)
Buffalo Ss.
66 Brush Creek Ls
Brush Creek C.
65 U. Mahoning Ss.
Sutton Ls.
Mahoning C.
Lr. Mahoning Ss.
64 U. Freeport C.
U. Freeport Ls.
63 U. Freeport Ss.
Lr. Freeport C.
Lr. Freeport Ls.
Lr. Freeport Ss.
62 U. Kittanning "R." C.
U. Kittanning C.
Johnstown Ls.
61 U. East Lynn Ss.
M. Kittanning C.
East Lynn Ss.
60 Lr. Kittanning C
Vonport Ls
59 Kittanning Ss
Clarion C.
Pottsville – Kanawha Group
58 Homewood Ss.
Stockton "A" C.
Konawha Black Flint.
Stockton C.
57 U. Coalburg Ss.
Coalburg "A" C
Coalburg C.
(Quakertown Rider)
56 Lt. Coalburg C.
Lr. Coalburg Ss.
55 Buffalo Creek C.
Buffalo Creek Ls.
54 U. Winifrede Ss.
Winifrede C.
(Quakertown ?)
53 Lr. Winifrede C.
52 Lr. Winifrede Ss.
Chilton "A" C
Winifrede Ls.
U. Chilton Ss.
51 Chilton "Rider" C.
Chilton C.
50 Lr. Chilton Ss.
Lt. Chilton C.
49 Hernshaw Ss.
Hernshaw C.
Williamson Ss.
48 Dingess Sh. & Ls.
47 Dingess Ss.
Williamson C
U Cedar Grove Ss.
46 Seth Ls
Cedar Grove C.
45 M. Cedar Grove Ss
Lr. Cedar Grove C
44 Peerless Ss.
Alma "A" C
Alma C
Sub-Stages or Cycles
of
Monongahela
Conemaugh
Allegheny
and
Upper Fourth of
Pottsville
of the
PENNSYLVANIAN SYSTEM
Interpretation of
David B. Reger
May 1, 1930

Fig. 51.

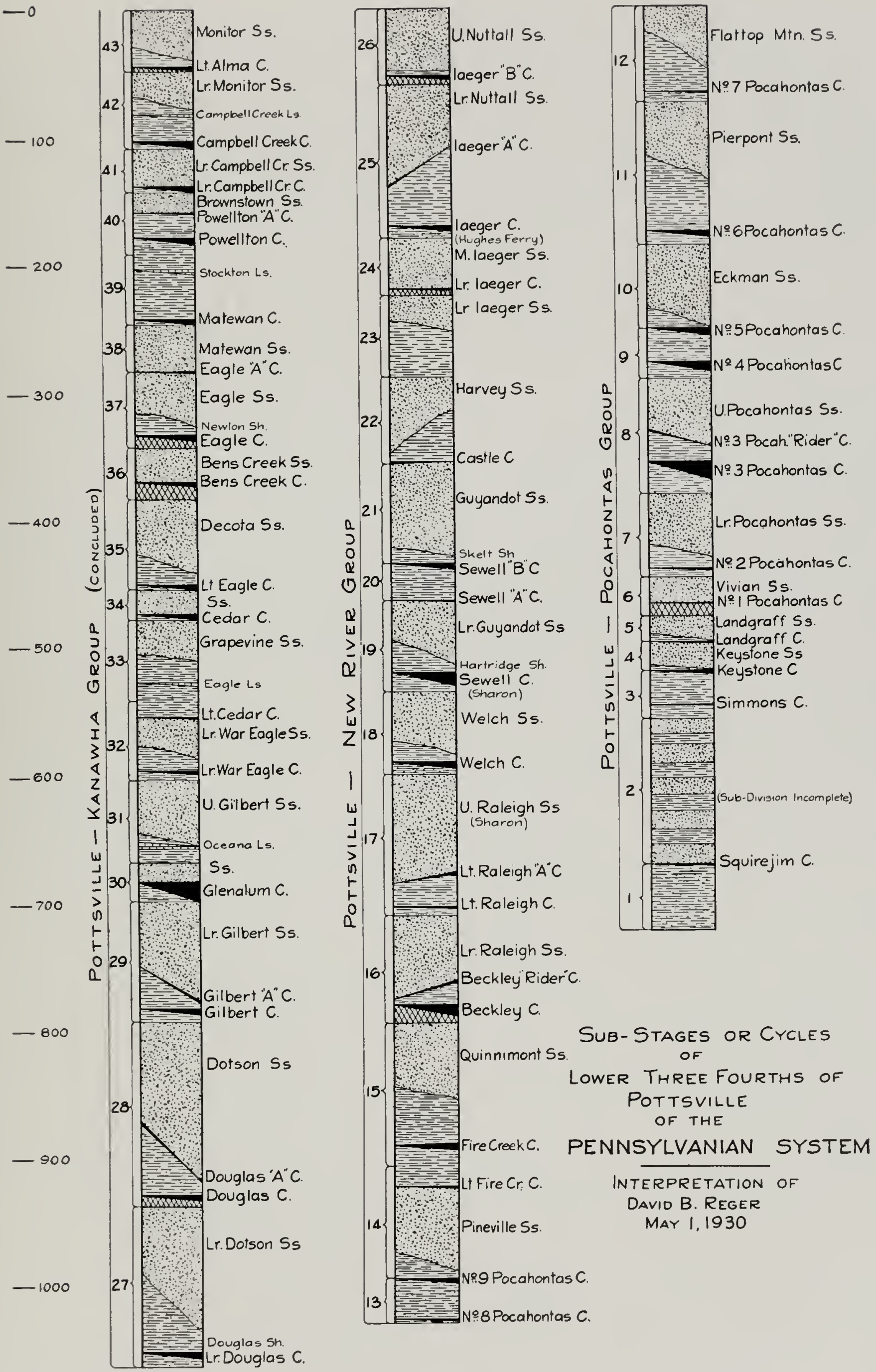

0
100
200
300
400
500
600
700
800
900
1000
Pottsville — Kanawha Group (Concluded)
Monitor Ss.
Lt. Alma C.
Lr. Monitor Ss.
Campbell Creek Ls.
Campbell Creek C.
Lr. Campbell Cr. Ss.
Lr. Campbell Cr. C.
Brownstown Ss.
Powellton "A" C.
Powellton C.
Stockton Ls.
Matewan C.
Matewan Ss.
Eagle "A" C.
Eagle Ss.
Newlon Sh.
Eagle C.
Bens Creek Ss.
Bens Creek C.
Decota Ss.
Lt Eagle C.
Ss.
Cedar C.
Grapevine Ss.
Eagle Ls
Lt. Cedar C.
Lr. War Eagle Ss.
Lr. War Eagle C.
U. Gilbert Ss.
Oceana Ls.
Ss.
Glenalum C.
Lr. Gilbert Ss.
Gilbert "A" C.
Gilbert C.
Dotson Ss
Douglas "A" C.
Douglas C.
Lr. Dotson Ss
Douglas Sh.
Lr. Douglas C.
Pottsville — New River Group
U. Nuttall Ss.
Iaeger "B" C.
Lr. Nuttall Ss.
Iaeger "A" C.
Iaeger C.
(Hughes Ferry)
M. Iaeger Ss.
Lr. Iaeger C.
Lr Iaeger Ss.
Harvey Ss.
Castle C
Guyandot Ss.
Skelt Sh
Sewell "B" C
Sewell "A" C.
Lr. Guyandot Ss
Hartridge Sh.
Sewell C.
(Sharon)
Welch Ss.
Welch C.
U. Raleigh Ss
(Sharon)
Lt. Raleigh "A" C
Lt. Raleigh C.
Lr. Raleigh Ss.
Beckley Rider C.
Beckley C.
Quinnimont Ss.
Fire Creek C.
Lt Fire Cr. C.
Pineville Ss.
Nº 9 Pocahontas C.
Nº 8 Pocahontas C.
Pottsville — Pocahontas Group
Flattop Mtn. Ss.
Nº 7 Pocahontas C.
Pierpont Ss.
Nº 6 Pocahontas C.
Eckman Ss.
Nº 5 Pocahontas C.
Nº 4 Pocahontas C
U. Pocahontas Ss.
Nº 3 Pocah. "Rider" C.
Nº 3 Pocahontas C.
Lr. Pocahontas Ss.
Nº 2 Pocahontas C.
Vivian Ss.
Nº 1 Pocahontas C
Landgraff Ss.
Landgraff C.
Keystone Ss
Keystone C
Simmons C.
(Sub-Division Incomplete)
Squirejim C.
Sub-Stages or Cycles of Lower Three Fourths of Pottsville of the Pennsylvanian System
Interpretation of David B. Reger May 1, 1930

Fig. 52.

PHANTOM SECTIONS

Assuming that a law of cyclical succession has been established for the stratigraphy of the Pennsylvanian system for which due credit is shared with Udden, Weller, Stout, and others, and that it has already been sufficiently studied to know the maximum number of sub-stages or cycles which it contains, I now propose to introduce the principle of the *phantom section.* A phantom section may be defined as a compilation which represents the maximum possible subdivisions of any series or group of rocks, and in which all members known or described are recognized as real and all members not yet known or described are regarded as *phantoms.*

These phantom members of the geologic world are analogous to the heavenly bodies which may be predicted by astronomers long in advance of their actual discovery and to the elements of the chemical world many of which have been anticipated and even partly described before their actual isolation in the laboratory.

Such a section may scarcely be compiled for any of the Pennsylvanian series, however, without first revising to some extent the present hap-hazard nomenclature. This difficulty is frankly met by making such a revision in the text of the phantom section. Present limitations of time and space will not permit a study of the entire Pennsylvanian system but for purposes of illustration and discussion the Monongahela series is selected and its phantom section, as revised with respect to nomenclature and possible new members, could be made to read as follows:

TABLE 16.—*Phantom section of the Monongahela series for West Virginia*

(Arranged in descending stratigraphic order and showing parenthetic italic revisions of geographic names for each sub-stage or cycle and also probable, or phantom, new members which remain to be discovered.)

	Thickness *Feet*	Total *Feet*
Sandstone, Waynesburg (heretofore, classified with the Dunkard series of the Permian), buff, massive, coarse, often conglomeratic	30 to 40	40
(Ridercoal, *Waynesburg,* phantom)	.. ..	40
(Overshale B, *Waynesburg,* phantom)	.. ..	40
Overlimestone, Elm Grove *(Waynesburg),* dark, flaggy, fresh-water, with fish teeth	5 to 0	40
Overshale A, Cassville (*Waynesburg,* formerly in Dunkard series), dark, fissile, sandy, with abundant plant fossils	10 to 5	45
Coal, *Waynesburg,* multiple-bedded, with fossil cockroaches in partings	0 to 5	50
Undershale B *(Waynesburg),* gray or red	15 to 10	60
(Underlimestone, *Waynesburg,* phantom)	.. ..	60
(Undershale A, *Waynesburg,* phantom)	.. ..	60
Sandstone, Gilboy, gray or green	10 to 30	90
(Ridercoal, *Gilboy,* phantom)	.. ..	90

	Thickness Feet	Total Feet
Overshale B, *Gilboy,* sandy	25 to 5	95
(Overlimestone, *Gilboy,* phantom)	.. ..	95
(Overshale A, *Gilboy,* phantom)	.. ..	95
Coal, Little Waynesburg *(Gilboy)*	0 to 1	96
(Undershale B, *Gilboy,* phantom)	.. ..	96
Underlimestone, Waynesburg *(Gilboy),* gray, fresh-water	0 to 4	100
Undershale A *(Gilboy)*	13	113
Sandstone, Uniontown, gray or green	20 to 35	148
(Ridercoal, *Uniontown,* phantom)	.. ..	148
Overshale B, Annabelle *(Uniontown),* brown	15 to 0	148
(Overlimestone, *Uniontown,* phantom)	.. ..	148
(Overshale A, *Uniontown,* phantom)	.. ..	148
Coal, Uniontown, multiple-bedded	0 to 2	150
Undershale B *(Uniontown),* gray or red	10	160
Underlimestone, Uniontown, gray, fresh-water	0 to 15	175
Undershale A, *Uniontown,* red or green, with thin sandstones and limestones	59 to 44	219
Sandstone, Arnoldsburg, gray or green	30 to 25	244
(Ridercoal, *Arnoldsburg,* phantom)	.. ..	244
Overshale B *(Arnoldsburg),* sandy or carbonaceous	0 to 5	249
(Overlimestone, *Arnoldsburg,* phantom)	.. ..	249
(Overshale A, *Arnoldsburg,* phantom)	.. ..	249
Coal, Lower Uniontown *(Arnoldsburg)*	0 to 1	250
(Undershale B, *Arnoldsburg,* phantom)	.. ..	250
Limestone, Arnoldsburg, yellow, fresh-water	5 to 0	250
Undershale A, Fulton *(Arnoldsburg)*	0 to 5	255
(Sandstone, *Benwood,* phantom)	.. ..	255
(Ridercoal, *Benwood,* phantom)	.. ..	255
(Overshale B, *Benwood,* phantom)	.. ..	255
(Overlimestone, *Benwood,* phantom)	.. ..	255
(Overshale A, *Benwood,* phantom)	.. ..	255
(Coal, *Benwood,* phantom)	.. ..	255
(Undershale B, *Benwood,* phantom)	.. ..	255
Underlimestone, Benwood, gray, fresh-water	5 to 65	320
(Undershale A, *Benwood,* phantom)	.. ..	320
Sandstone, Sewickley, gray	10 to 25	345
(Ridercoal, *Sewickley,* phantom)	.. ..	345
Overshale B *(Sewickley)* sandy or carbonaceous	15 to 0	345
(Overlimestone, *Sewickley,* phantom)	.. ..	345
(Overshale A, *Sewickley,* phantom)	.. ..	345
Coal, Sewickley	0 to 5	350
Undershale B *(Sewickley),* fireclay shale	10 to 5	355
(Underlimestone, *Sewickley,* phantom)	.. ..	355
(Undershale A, *Sewickley,* phantom)	.. ..	355
Sandstone, Lower Sewickley *(Gore),* gray	10 to 20	375
(Ridercoal, *Gore,* phantom)	.. ..	375
Overshale B *(Gore),* sandy or carbonaceous	10 to 0	375
(Overlimestone, *Gore,* phantom)	.. ..	375

	Thickness Feet			Total Feet
(Overshale A, *Gore,* phantom)	..		..	375
Coal, Lower Sewickley *(Gore)*	2	to	0	375
(Undershale B, *Gore,* phantom)	..		..	375
Underlimestone, Sewickley *(Gore),* gray or yellow, fresh-water	0	to	33	408
(Undershale A, *Gore,* phantom)	..		..	408
Sandstone, Cedarville *(Redstone),* gray or green	40	to	10	418
(Ridercoal, *Redstone,* phantom)	..		..	418
Overshale B *(Redstone),* sandy or carbonaceous	5	to	0	418
(Overlimestone *(Redstone),* phantom)	..		..	418
(Overshale A *(Redstone),* phantom)	..		..	418
Coal, Redstone	0	to	4	422
Undershale B, *Redstone,* fireclay shale	2	to	0	422
(Underlimestone, *Redstone,* phantom)	..		..	422
(Undershale A, *Redstone,* phantom)	..		..	422
Sandstone, Weston, gray or green	20	to	0	422
(Ridercoal, *Weston,* phantom)	..		..	422
(Overshale B, *Weston,* phantom)	..		..	422
(Overlimestone, *Weston,* phantom)	..		..	422
(Overshale A, *Weston,* phantom)	..		..	422
(Coal, *Weston,* phantom)	..		..	422
(Undershale B, *Weston,* phantom)	..		..	422
Limestone, Redstone *(Weston),* yellow, fresh-water	0	to	5	427
(Undershale A, *Weston,* phantom)	..		..	427
Sandstone, Pittsburgh, gray	0	to	15	442
(Ridercoal, *Pittsburgh,* phantom)	..		..	442
(Overshale B, Weston (*Pittsburgh*), limy			5	447
(Overlimestone, *Pittsburgh,* phantom)	..		..	447
(Overshale A, *Pittsburgh,* phantom)	..		..	447
Coal, Pittsburgh			8	455
Undershale B (*Pittsburgh,* heretofore classified with the Conemaugh), fireclay shale			5	460
Underlimestone, Fairfax (*Pittsburgh,* heretofore classified with the Conemaugh), lenticular, fresh-water	0	to	2	462
(Undershale A, *Pittsburgh,* phantom)	..		..	462

In the above section it is evident that a student, in order to know the succession of members in the Monongahela, need learn only ten formation names and the relative positions of the different types of material which should be invariable for all cycles. These relative positions within the cycle are made easy by the simple German expedient of combining two words such as "Ridercoal", "overshale", "undershale", "overlimestone", and "underlimestone". The principle of geographic names is fully preserved and, with few exceptions, the original names of sandstones and coals as established by earlier geologists are retained. The names of two sandstones, three minor coals and five limestones would be changed. Certain changes are also made in the names of shales but these should be of only trifling consequence. In order to make all the cycles complete the Waynesburg sandstone and Cassville shale have been removed from the Dunkard series of the Permian system but no great violence is done, inasmuch as the plants in the roof shales of the Waynesburg and Uniontown coals are so essentially similar that the two coals were long ago confused by Fontaine and I. C. White in certain long distance correlations. At the bottom of the section certain rather trivial members are absorbed from the underlying Conemaugh series.

In actual practice the phantom members of the section should, in the course of years, be reduced mainly to real entities and it is conceivable that the whole section might eventually become real, although there are probable unconformities which may not permit full discovery of all phantom members. As a present fact any geologist familiar with geologic literature of the Monongahela series could now put into the real section many of the phantom names by a mere examination of published sections and borings.

The need of the term "Ridercoal" is scarcely apparent in the Monongahela series but in certain other series, the Pottsville for instance, the Rider or "A" coal is the rule rather than the exception and hence the name is required. A "Rider" or "A" coal, it should be explained, almost invariably lies directly under a sandstone without intervening shale. The terms "Overshale A", "Overshale B", "Undershale A" and "Undershale B" are necessary because it is always impossible to know whether the "Overlimestones" and "Underlimestones" will be found above, below or within their accompanying shales. In cases where a limestone is still phantom the shales should be called "undershale" or "overshale" without a following "A" or "B" until the discovery of the limestone makes a division possible.

There is a possibility that an additional cycle may be found in the Uniontown Undershale A, on account of its rather complex composition and thickness. If so, the only required revision will be the addition of one more formation name with attendant phantoms and no violence will be done to the remainder of the section.

The use of the phantom section is possible in any series or systems of rocks where cyclical sub-stages can be recognized. In the Appalachian region it is not only applicable to the entire Pennsylvanian system but also to the overlying Permian and underlying Mississippian systems. The writer has used the principle of the phantom section in correlation work for many years and has had in mind the preparation of such sections for the three systems mentioned for his own State. At some early date these phantom sections may be expected to appear.

PENNSYLVANIAN CYCLES IN PENNSYLVANIA

By George H. Ashley[1]

Such a broadside as this symposium on the fascinating problem of Coal Measure sedimentation ought to throw some light on that problem. After thirty-four years study of that problem the writer is not sure that he knows much more about it now than he knew thirty years ago, although since that time it has been his privilege to examine many coal fields from Rhode Island and Tennessee to Texas and California.

Certain facts seem well established. (1) The coal itself is composed of plant material, most of which grew above water level rather than below, judged by the abundance of woody material in the coal and the land or swamp-growing character of most of the plants identified. (2) The coal beds of the Appalachian-Interior regions were deposited about at sea level and probably above rather than below, judged by the plants found in them and in the associated rocks. Interbedded limestones and shales containing marine shells indicate that the coal was formed but little if any above sea level, whereas interbedded gritty or pebbly beds indicate the temporary presence of rivers or shores. (3) The coal beds are separated by other beds and surfaces which indicate that between the laying down of one coal bed and the next the earth's surface did not remain at sea level but was depressed or elevated by amounts to be measured in scores, if not hundreds of feet. (4) The presence of the coal beds—to the number of 100 or more in West Virginia, 68 in Pennsylvania, and at least 34 in Indiana—is clear evidence that the physical conditions necessary to the laying down of the coal recurred time and again.

The special problem before this symposium is: were these recurrences rhythmic or cyclical in character? My own answer is "yes" to the extent of the coal and its underlying clay, and "no" beyond that. It is true the same succession of beds from one coal to the next may be pointed out here and there.

I have before me a stratigraphic chart of the Indiana coal field[2] containing 117 columnar sections, mostly representing records of core drillings, and covering the field from Danville, Illinois, to Evansville, Indiana. I also have before me a group of charts[3] of similar columnar sections from the Pennsylvania Coal Measures containing hundreds of sections; also a single

[1] State Geologist, Pennsylvanian Geological Survey, Harrisburg.

[2] Thirty-third Ann. Rep. Dept. of Geology and Nat. Res. of Indiana, p. 54, 1908.

[3] Sisler, J. D., Bituminous coal fields of Pennsylvania: Penna. Geol. Survey Bull. M6, Pt. II, Top. and Geol. Survey of Pennsylvania, 1926.

combined section of the Coal Measures of West Virginia, issued by the Geological Survey of West Virginia.

A study of these charts seems to show that although here and there are similar successions of rock beds, on the whole the sections are characterized by differences rather than by similarities. One coal has limestone above, the next has limestone below and the next no limestone above or below. A group of 50 sections between two certainly recognized coal beds shows one sandstone, two sandstones, three sandstones or none; one limestone, two limestones or none. Some of the sections show from one to three intermediate thin beds of coal, each with its underlying clay, whereas most of the sections show no intermediate coals.

Going into detail we find coal beds splitting into two or more benches which may become 50 or more feet apart, as with the Moshannon bed in Clearfield County, Pennsylvania, the benches separated by sandstones, shales, and possibly clays. If drill records of a single large tract be plotted to scale and set up in their relative position, one is again struck with the remarkable variability of the strata from drill hole to drill hole.[4] Certainly that is true of the Coal Measures in Pennsylvania, and I think it is equally true in Indiana.

This seeming variability is due in part, if not largely, to the meagerness of the rock record, owing to two causes. First, as we examine these rocks in the field or study the well sections we commonly think of the records as though they were complete for the area studied. My own work has convinced me that the records we see are only meager representatives of the full record if we could bring together in one section all of the elements of all of the sections. For example (if I may be permitted to step out of my own dooryard), the No. 5 bed of Indiana and Illinois is commonly overlain by a black sheety shale containing pelagic sea shells. We commonly think of the laying down of the coal having been followed immediately by an incursion of the sea. But in Pike County, Indiana, and the "low-sulphur district" of Illinois, a thick body of brown, plant-bearing shales intervene between the coal and black marine shale, without apparently affecting the thickness of the black shale. Obviously the brown shale represents a partial record of the events following the laying down of the coal and preceding the incursion of the sea. The same bed splits in eastern Warwick County, Indiana, without apparent loss of thickness. A bed that splits in one place may carry a streak of bony coal 1 inch thick or less where not split as a reminder that there is a skeleton in the closet if one cared to open the door.

It is astonishing how minor elements of the section may be traced long distances, appearing and disappearing. Limestone nodules as big as apples occurring occasionally at one horizon in an area may almost certainly represent a solid continuous limestone in another area. I have even correlated

---

[4] Ibid., Bull. M6, Pt. I, pp. 82-85, 105, 106.

scattered thin sandstone lenses in shales in the railroad cuts around Pittsburgh with the Jane Lew sandstone of West Virginia. In eastern Kentucky a 4-inch layer of black flint clay is correlated with a flint clay in a road-cut opposite the railroad station at Clarion, Pennsylvania. Such correlations may seem fanciful until, having all of these elements in mind, you find yourself picking them out in section after section, sometimes strong and sometimes very faint. Often there is no trace of them. If all of these elements could be put into one section with their greatest thickness it is probable that our section would be ten or twenty times as long as at present. The variable presence or absence of these elements in any one section largely accounts for seeming differences between adjoining sections.

The other reason for the variability of the section from point to point is the amount of rock removed during the frequent temporary uplifts so characteristic of the Coal Measures. I have sometimes thought that every sandstone in the Coal Measures follows a period of uplift, erosion, and depression. So common is this relation that it might almost be listed as a third element in the cyclical sedimentation of the Coal Measures. Although it may be possible to definitely put one's finger on only a few widespread horizons at which there has commonly been uplift followed by stream erosion and that by down-sinking and deposit of sand, nearly every good exposure of the Coal Measure sandstones is likely to show an irregular base for the sandstone and often apparent unconformity within the sandstone itself.

In contrast with these often widespread and extremely variable elements of the Coal Measures, the coal beds and underlying clays present many features of uniformity and persistence and give evidence of a certain rythmic recurrence of similar physiographic conditions.

Leaving out of account cannel coal, which appears to be commonly the result of accumulation in open water places in the coal swamps, coal beds have generally been laid down under one of three conditions: (1) in basins or channels, the channels being erosion channels excavated by surface water, and the basins either erosion basins or basins of slight folding due to local depression of the underlying surface; (2) in widespread swamps which follow a remarkable uniformity of history and physiographic conditions, and (3) in widespread swamps subject to a great variety of local conditions.

Typical of the first class of deposits are the "block coal" beds of Indiana and the Sharon coal of Pennsylvania and Ohio. In these deposits the bed is commonly thick in the middle of the basin or channel and thin on the edges. Similar conditions may effect a large number of basins, as shown by the writer's 1898 report on the block coal of Indiana, or each basin may have a history different from that of any other. In the second type a coal bed may cover hundreds or thousands of square miles with remarkable uniformity of thickness, quality and bed section, as illustrated by the Pittsburgh coal of

Pennsylvania, the "blue band" coal of Illinois, the No. 6 coal of Sullivan County, Indiana, or certain beds of West Virginia and Tennessee. It is obvious here that earth movements of depression or elevation had been remarkably uniform over the large area involved. In the third type of deposits, although coal-forming conditions have been widespread, local conditions have varied from place to place so that the resulting coal bed varies in thickness and character, and in the partings and benches even within a single mine. This is the most common type.

Characteristically associated with the coal beds, in the fields under study, are argillaceous deposits in three positions; under the coal, within the coal, and on top of the coal. The origin of these clays under and within the coal beds have been long a subject of discussion. The writer's experience has led him to believe that all three deposits are of similar origin, except that the beds below or in the coal have been affected by plant growth and the acids resulting from plant growth, and that all were derived by the settling of fine mud in shallow water. Whether this fine mud was distributed as dust by wind or water currents is not clear. The evidences for this conclusion are as follows. (1) The clays under the coals and forming partings in the coal beds are commonly similar except in thickness, and occasionally are similar in that respect also. (2) The underclay commonly appears to be independent of the underlying rock. The same bed of clay may maintain its thickness and character whether the underlying rock is sandstone, limestone, shale, flint, or coal. In basins such as those in the Brazil block coal fields of Indiana the underclay is commonly confined to the center of the basin, being thick in the center of the basin and edging out on the flanks of the basin. If the underlying rock forming the basin is sandstone, it commonly differs from the same sandstone elsewhere in much the same way as the underclay differs from the roof clay; that is, its color and fluxes have been leached out, presumably by acids derived from the plant growth. (3) If cannel coal is associated with bituminous coal and occurs at the bottom of the bed the underlying rock is commonly ordinary shale apparently not having been leached out. (4) The underclay is usually fairly characteristic of the several beds and is sometimes divided into distinct benches of different character or encloses layers of other rocks such as the Upper Freeport limestone of Pennsylvania, which occurs under the Upper Freeport coal bed and which is frequently found between two layers of clay. The layers of rock separating benches of a coal bed commonly consist of clay with little or no carbonaceous matter in it, but may consist of shale, bone, sandstone, flint clay, pyrite, or iron ore. The parting material may be quite free from carbonaceous matter, or as bone may be largely carbonaceous. One of the most baffling problems of Coal Measures stratigraphy is to account for the presence of these thin layers of clay or other materials, often only a fraction of an inch thick, between the benches of a coal bed.

Such a thin parting may extend over an area of hundreds of square miles with remarkable uniformity of thickness and character. It is possible, if not probable, that detailed areal studies will show a definite thickening or thinning in certain directions. In some coal beds are found "smooth" or "knife edge" partings in which the coal parts with a smooth surface. Obviously the coal-forming conditions stopped for a time at such a parting and later were resumed without any extraneous matter being laid down.

This brief review may be summarized as follows. Judging from conditions in Pennsylvania and Indiana the Appalachian and Eastern Interior fields during Pennsylvanian time were characterized by slow, widespread sinking with many long pauses and frequent slight uplifts followed by surface erosion. In general the movement of sinking was remarkably uniform so that similar conditions often existed over a large part of the coal-field area. At the same time these movements in the main appear to have been very slight at any one time except for one uplift seen in Indiana and Illinois in the upper Coal Measures, which permitted the cutting of stream channels 150 feet deep. In general, such channels are less than 40 feet deep. The presence of coarse grits or conglomerates far out in the midst of the coal area suggests that some of these movements may have amounted to several hundred feet near the edge of the field to allow for the coarse material having been carried so far out from the highland. To account for the rapid alternation of coarse and fine sediments with periods of no sedimentation it is necessary to assume much more pronounced movements outside of and adjoining the coal field area in the areas from which these materials were obtained.

In general the beds of rock in Pennsylvania thin from east to west from 3,500 feet in the Southern Anthracite field to 2,500 feet in southwestern Pennsylvania, and still less farther west. Conditions in Indiana and Ohio indicate that the Cincinnati arch may have remained above sea level during early, or possibly during all of Pennsylvanian time. The writer's recent study of comprehensive stratigraphic charts reveals no persistent order or succession of the Coal Measure rocks outside of the common and usual association of coal beds with argillaceous deposits below, within, and above the coal beds. The deposits below and within the coal beds commonly have been changed to nonlaminated clays, low in fluxing material.

Afternoon Session, May 1st

Dr. W. S. Bayley, *Presiding*

PENNSYLVANIAN CYCLES IN THE NORTHERN MID-CONTINENT REGION

By Raymond C. Moore[1]

INTRODUCTION

For the purposes of this symposium the Pennsylvanian strata of the northern mid-continent region may be defined to include the outcrops in Iowa, western Missouri, Nebraska, Kansas, and at least northern Oklahoma. I have examined most of the Pennsylvanian strata in these states, but only in part of the area and part of the section have I completed detailed stratigraphic studies. These parts include the Pennsylvanian of eastern Kansas and northern Oklahoma and represent chiefly the upper part of the Pennsylvanian system. Some of these studies, including visits to exposures in Nebraska and western Missouri, were made in company with Dr. G. E. Condra, state geologist of Nebraska.

GENERAL CHARACTERS OF THE PROVINCE

The Pennsylvanian strata of the northern mid-continent region consist of comparatively thin formations of alternating shale, limestone, sandstone and a few coal beds, the aggregate thickness in most places being less than 3,000 feet. The beds dip gently away from the Ozarks, but in Iowa and southeastern Nebraska the dip is locally changed in direction. The outstanding characters of the section are the relative importance of marine sediments and the extreme persistence and lateral uniformity of most of the stratigraphic units.

Marine Deposits

The thickness of marine deposits in the Pennsylvanian strata of the northern mid-continent region is proportionately much greater than in Illinois or states farther east. Limestone occurs in many beds, and in some parts of the region the aggregate thickness of Pennsylvanian limestone is almost 500 feet. In addition, many of the shale and some of the sandstone beds are marine, as indicated by the presence of more or less abundant marine fossils.

[1] State Geologist of Kansas, and Head, Department of Geology, University of Kansas.

On the other hand, the Pennsylvanian rocks of this region are by no means exclusively marine, for coal beds and clastic rocks containing land plant fossils are found at many horizons. In part of the section there appears to be a definite and regular alternation between marine and non-marine sediments, but nevertheless, the sea appears to have been more persistently and frequently present in this region than in the provinces to the east.

Lateral Persistence of Beds

In contrast to the extreme irregularity and lenticular form of sedimentary units that has generally but erroneously been suggested by reconnaissance

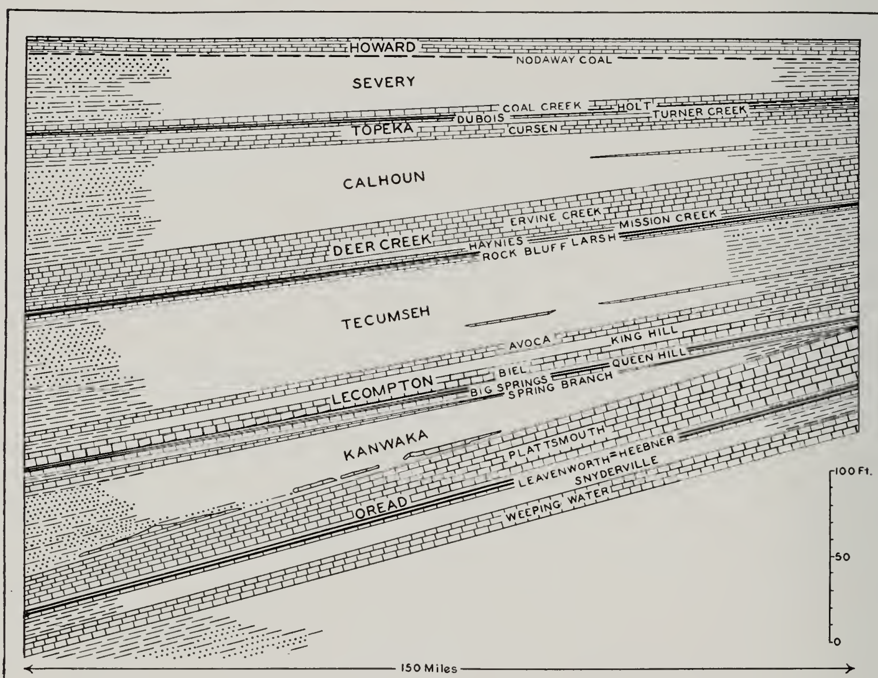


Fig. 53. Diagram representing portion of upper Pennsylvanian strata in Kansas and Nebraska, showing regularity of sequence and persistence of thin stratigraphic units and the northward thinning of the shales and convergence of the limestones.

examination of the Pennsylvanian deposits of North America, most of the beds in the northern mid-continent region are surprisingly persistent. This applies not only to limestones but also to certain thin shale and coal beds. It is not so generally true of sandstones. Detailed stratigraphic studies which are now being made show not only that limestone and shale formations, 30 to 50 feet thick, may be followed for as much as 400 or 500 miles along the outcrop without finding great variation, but that minute subdivisions of these formations may be equally persistent. For example, one limestone bed 6 to 24 inches thick is known to be continuous from Iowa and Nebraska through Missouri and Kansas into northern Oklahoma; and there are many similar examples. In a number of cases thin coal beds that in many places are less than a half inch thick have been traced similar distances. A micro-fossil zone ¼ to ½ inch thick is identified in sections 100 miles apart. These observations point to widespread uniformity in the conditions of sedimentation at any one time, but the numerous changes in the character of the beds in vertical sequence indicate frequent changes in the physical environment.

Regional Change in Character and Thickness

Comparison of the Pennsylvanian rocks in southeastern Nebraska with those in Kansas and Oklahoma or in parts of Missouri shows that the amount of limestone is relatively greater, the shale and sandstone less, and that the total thickness of the rocks is less in the northwesterly areas than to the south. The increased thickness southward is seen chiefly in the shale and sandstone divisions which expand rapidly in Oklahoma, reaching a maximum in the southern part of the state where in some places the total thickness of the Pennsylvanian deposits may exceed 25,000 feet.

CLASSIFICATION OF THE PENNSYLVANIAN BEDS IN THE NORTHERN MID-CONTINENT REGION

The major divisions in the stratigraphic classification of Pennsylvanian beds in the northern mid-continent region are based partly on lithology and physiographic expression and partly on faunal characters. In some reports these divisions have been called formations, and in others they are designated as groups. For various reasons the latter seems preferable. Certain parts of this classification seem to have no particular validity, yet through usage they have become well established in the northern states of the western interior coal basin.

The lowest Pennsylvanian rocks of the northern mid-continent field are called the Cherokee shale. This formation has an average thickness of 300 to 400 feet but it is much thinner in parts of Nebraska, and southward in Oklahoma it thickens to 10,000 feet or more. The Cherokee sediments consist predominantly of shale, but include a number of important sandstone beds and lenses; coal beds are fairly numerous, widespread, and commercially valuable. Fossil evidence indicates that the Cherokee is mainly of Pottsville age but may contain in the upper part beds of Allegheny age.

The next division, called the Marmaton group, or in Missouri the Henrietta and Pleasanton formations, differs from the Cherokee mainly in the presence of two or three widely persistent limestone units. The Marmaton beds range in thickness from about 150 feet or less in the north to more than 300 feet in the south. The basal formation is the Fort Scott limestone, or as commonly termed by drillers in the oil fields, the "Oswego lime." It is a valuable, extensively used stratigraphic marker, as it is one of the most widely persistent, definitely recognized beds in the northern mid-continent area. The Fort Scott limestone is known to crop out from east-central Oklahoma northward across eastern Kansas and northwestern Missouri to Iowa. It is practically continuous and is definitely correlated with the limestone above the Herrin or No. 6 coal of Illinois. Underground the Fort Scott has been identified throughout much of northern Oklahoma and Kansas as far as 100 miles west of the outcrop. The upper Marmaton, or Pleasanton, consists mainly of shale and sandstone, containing some very large and striking channel sandstone deposits, such as the Warrensburg and Moberly sands in Missouri.

The Kansas City group is distinguished mainly by the prevalence of limestone. The total thickness ranges from about 200 to 250 feet. In parts of eastern Kansas and western Missouri the section is more than half made up of limestone. The shale beds are clayey to limy, and there are several very persistent layers of black slaty shale. There is very little sandstone in the formation.

The next stratigraphic unit, called the Lansing group, consists of about 100 to 150 feet of alternating shale and light colored limestone beds. In places, as on Kansas River, the section consists of almost solid limestone. In southern Kansas and extending into northern Oklahoma there is a very abrupt change from lime and shale to sandstone, and in Osage County, Oklahoma, much or all of the Lansing consists of sandstone.

The Douglas group consists mainly of shale and sandstone capped by the very persistent and prominent Oread limestone formation. The shale and sandstone are in part nonmarine and are more or less notably irregular. Coal is kown at two or more horizons. The thickness of the Douglas ranges from about 200 to 300 feet.

The Shawnee group consists of rather regularly alternating shale and limestone formations, the total thickness ranging from about 300 to more than 500 feet. The thicker shales average 50 to 100 feet in thickness, and are prevailingly sandy and micaceous. There are also thin but remarkably persistent shales associated with the limestones. The latter shale beds are clayey or limy, and some of them are black and slaty. The limestones consist of members or beds which are distinguished by lithologic and faunal peculiarities that are surprisingly persistent and uniform. There are two or more thin but extensive coal beds in the Shawnee group.

The Wabaunsee group consists of 400 to 500 feet of beds essentially like those of the Shawnee except that the limestones are thinner and somewhat more regularly distributed through the shale. Sandstone is much less prominent than in the Shawnee. There are a few thin but persistent coal beds.

EVIDENCE OF CYCLIC SEDIMENTATION

The most obvious regular repetition of beds found in the Pennsylvanian strata of the northern mid-continent region which may perhaps be indicative of cyclic conditions of sedimentation is seen in the regular alternation of shale and limestone beds and in the regular and peculiar sequence of certain types of limestone and shale in parts of this alternating series. This sequence of beds is more regular in some parts of the section than in others. The most definite representation is probably found in the upper Douglas and in the Shawnee groups. We may take the upper Douglas as a type. The uppermost formation of the Douglas group is called the Oread limestone. It is underlain by clayey to sandy shale with local shaly to somewhat massive sandstone called the Lawrence shale. Below that is another limestone and another sandy shale and sandstone.

Nonmarine Shale and Sandstone

Beginning with the Lawrence shale we may note the presence of sandstone and very sandy shale, most of which is highly micaceous. Physical characters, including bedding, local presence of mud cracks, current ripples, et cetera, indicate that these sediments were subaerial in origin rather than marine. The occasional fossils that are found consist of fragments of wood, of carbonaceous material including poorly preserved leaves, and very rarely of tracks of vertebrates. Swamp conditions are indicated by the occurrence of coal, and as at least two beds of coal are known, one very thin and unimportant, there may be a subordinate oscillation or change of conditions of sedimentation within the Lawrence shale unit. At least one zone of beautifully preserved plant fossils is known.

Marine Limestone and Shale Sequence

The Oread limestone consists of three limestone members separated by two shales, and in many places there is an additional limestone and shale member above the normal top member. These divisions may be described briefly in order from the base to the top.

(1) The lower limestone member consists of massive, somewhat impure, yellowish-brown limestone which has an average thickness of 4 to 8 feet. It contains more or less numerous marine fossils, although these are not generally as common as in the upper member. Chert is present very rarely. A typical character seen in weathered exposures is the oblique or

irregular, shelly, joint fractures. Distinctive features are the massive beds and the brownish color.

(2) The shale above the lower limestone is clayey, gray to yellowish, and 5 to 15 feet thick. It is generally nonfossiliferous but in places contains some marine fossils.

(3) The next limestone, commonly called the middle bed, consists of dense, bluish-gray, hard, brittle, massive limestone which is distinguished by its thinness and its mode of weathering in angular sharp-edged blocks which represent the entire thickness of the bed. For scores or even hundreds of miles along the outcrop the thickness is practically invariably 12 to 18 inches.

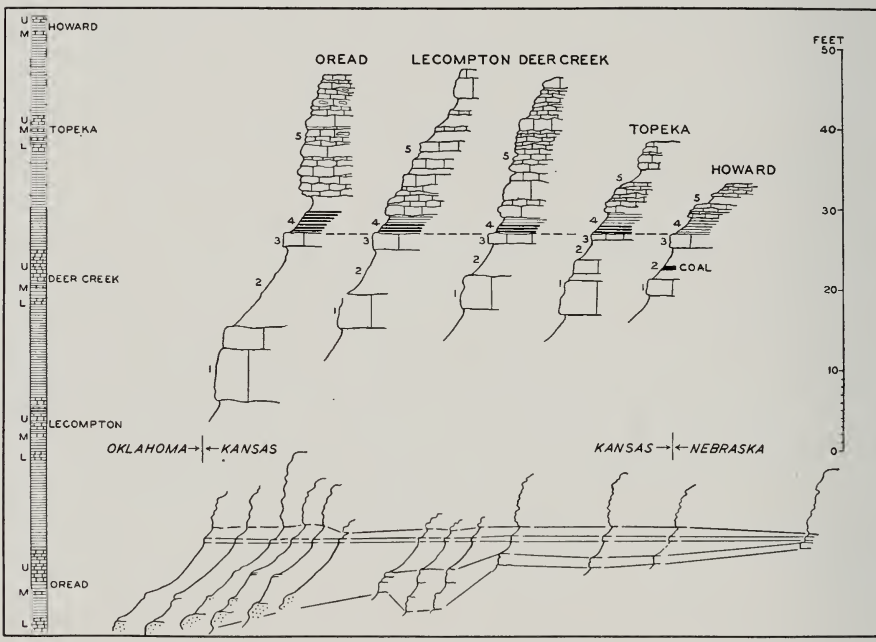


FIG. 54. Diagram showing typical sequence of limestone and shale units in limestone formations of the upper Pennsylvanian strata in the northern mid-continent region. The compared sections represent successive superposed limestone formations. In each are, (1) massive, brown limestone; (2) light colored shale; (3) blue, dense, blocky, massive limestone; (4) shale, lower part black, fissile; and (5) very light gray, thin and irregularly bedded, fine grained limestone. The lower part of the diagram shows a series of sections of the Deer Creek from Nebraska to Oklahoma showing thickening of the shale and change of the lower limestone to sandstone.

The bed contains marine fossils which, on account of the texture of the rock, are very difficult to collect. Distinctive features are the bluish color, dense texture, and occurrence as a single massive but thin layer.

(4) The shale above the thin middle limestone bed is about 3 to 5 feet thick and typically consists of two parts, a lower black fissile slaty shale and

an upper part consisting of gray to yellowish clayey shale. The black slaty shale may contain poorly preserved plant fragments and has yielded a few fossil insects. The upper shale has some marine fossils. The black fissile shale is a distinctive part of the sequence.

(5) The upper limestone is notably different from both of the lower ones in texture, bedding and thickness. The rock is very fine-grained, fairly pure and in part almost lithographic in texture, but commonly it contains fine veinlets or cross-sections of fossils showing crystalline calcite. The beds are thin and wavy, the dense lithographic-textured portions of the rock being separated by thin streaks of shaly limestone. The limestone thus appears quite nodular. Chert lenses and nodules are fairly common but not abundant. The color of the rock is very light gray, and on weathering it turns nearly white. The thickness of the limestone ranges from 15 to 30 feet.

(6) Where another limestone occurs a short distance above the thick upper Oread bed, the shale which separates them is variable. It is often sandy and in a few places contains impressions of marine fossils. It ranges in thickness from 6 inches to about 12 feet.

(7) This "super" limestone zone is characterized by marked irregularity in development and also, when found, in its lithology and bedding. In most cases it is a dense, hard, more or less oölitic and somewhat cross-bedded limestone, 2 to 8 feet thick, and the rock may be very solid and uniform or may be divided into thin beds a few inches each in thickness. Another phase which is about as common consists of fine-grained, dark, bluish, impure limestone. Commonly this zone contains abundant, beautifully preserved fossils.

Above this topmost limestone of the sequence occurs sandy shale and sandstone with plant fossils and coal which begins a new cycle or series of beds. Thus, the typical order of beds appears to be fairly thick sandstone and shale with nonmarine fossils and some coal followed by the sequence of limestone and shale which has been described.

As intimated, the minor stratigraphic divisions which make up this sequence are surprisingly persistent along the outcrop. Certain of the limestones have been traced for as much as 500 miles. However, in following the lowermost bed of the Oread from north to south it has been found that there is a transition from impure limestone to limy sandstone and to sandstone with little or no lime. This sandstone is a continuation of the lower lime, not of the shale above or below the limestone, and the sandstone persists for a very considerable distance.

Repetition of Sequences

The sequence of beds in the upper Douglas group is repeated with remarkable fidelity several times in other parts of the Pennsylvanian section

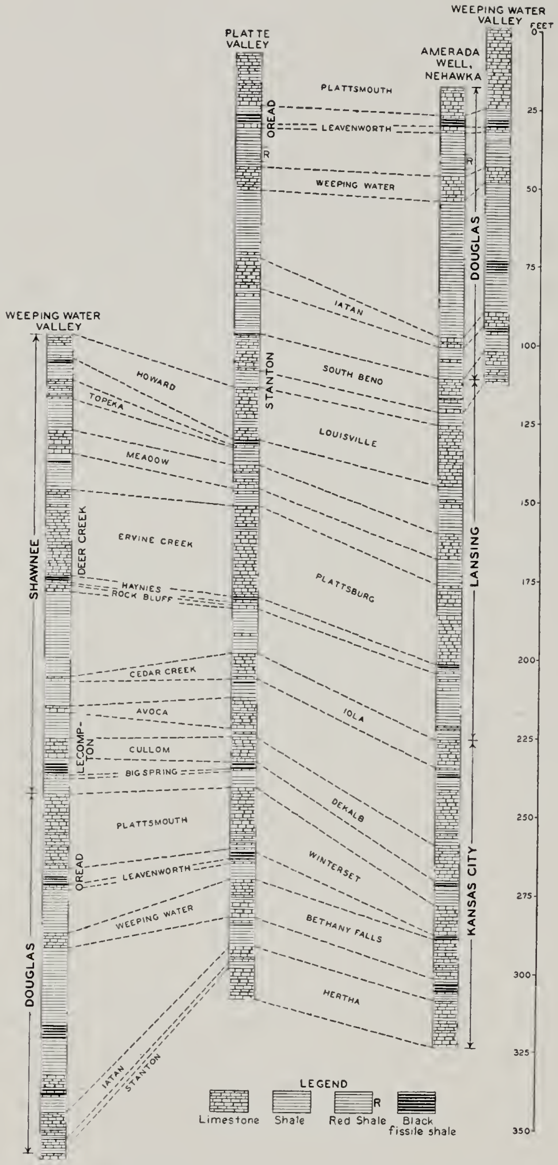


FIG. 55. Diagrammatic columnar sections of upper Pennsylvanian strata in southeastern Nebraska. The left-hand part of the diagram shows the upper part of the Weeping Water section as exposed along Weeping Water Creek, southeastern Nebraska, and the first published erroneous correlation of the strata exposed along the Platte Valley some miles to the north. The right-hand part of the diagram shows the lower part of the exposed Weeping Water section and the log of the Nehawka well with the correct correlation of the Platte Valley section.

of the northern mid-continent region. This is true to such an extent that on finding an exposure of a limestone bed with lithologic characters corresponding to those of "lower", "middle", "upper", or "super" divisions of the type sequence, search for associated members which should normally occur is commonly successful. Also, it is easily possible for a geologist engaged in reconnaissance study to mistake one group of beds representing the cycle for another that actually belongs some scores or hundreds of feet higher or lower stratigraphically. It is even possible in detailed work, where beds are not traceable continuously from one region to another, to match sequences of beds erroneously even though a considerable part of the section is involved. This was experienced in studying the Pennsylvanian beds of southeastern Nebraska. The complexity of the characters that are involved in the succession and the number of repetitions of these characters in proper order and in complete detail make it apparent that repetition of the described succession of beds is not fortuitous and meaningless.

On the other hand, by no means all of the Pennsylvanian rocks of this region can be fitted readily into such a cycle as has been described. It is true that there are repeated and fairly regular alternations from clastic to pure limestone deposits, and changes from marine to nonmarine sedimentation, but in many cases the limestones are single beds without the several members which appear in the described cycle.

SOURCES OF SEDIMENTS

The facts that the amount of clastic sediments increases regularly to the south as the rocks are traced from Nebraska to Oklahoma and that a distinctly greater proportion of sand occurs in the section southward, imply that the main source of sediments in the Pennsylvanian of the western interior basin lies to the south and perhaps the southeast. Locally in southern Oklahoma there are beds of conglomerates which were derived from the local mountain uplifts of that region, such as the Ouachita and Arbuckle mountains. The ultimate source of most of the terrigenous sediments in the Pennsylvanian strata of the northern mid-continent area was probably Llanoria, which may have joined Appalachia on the east.

The essential continuity of beds eastward suggests that some of the Pennsylvanian sediments of Kansas, Nebraska and Missouri may have been derived from the Appalachian country in the distant east. If, as seems likely, the formations and zones of the border portions of one basin can be identified in those of adjoining districts, the former continuity of the Pennsylvanian strata will be all but proved. It is true that the section is thicker in Kansas and Missouri than in Illinois, but this appears to be due mainly to the presence of younger Pennsylvanian deposits in the western region. There is little or no evidence pointing to sediments derived from the north or west at this time. Indeed, subsurface studies in western Kansas show that at least in some places the Pennsylvanian strata overlap in a western direction so that beds of Marmaton or Kansas City age rest directly on much older rocks.

SIGNIFICANCE OF CYCLES OF SEDIMENTATION

The general oscillation from nonmarine to marine sediments and vice versa which appears in parts of the Pennsylvanian system of the northern mid-continent region obviously means an alternating presence and absence of the shallow continental sea. The nonmarine beds appear largely to have been deposited by low-gradient streams. Channels that are now filled by the so-called "shoe-string" sands clearly represent temporary erosion. Some of these channel-fillings, with convex bottoms and even horizontal tops, are traced for several miles in eastern Kansas to points where the sand becomes more widespread and extends at approximate right angles to the course of the channel "shoe-string." This extension of the sand body has a convex upper surface and seems to represent a coastal bar.[2] In general, conditions appear to have favored sedimentation and the slow steady accumulation of vast sheets of sediments. The marine deposits of course record advances of the sea. The alternation of marine and nonmarine units implies an oscillation or rhythmic advance and retreat of the sea. Such oscillation may have been caused by periodic subsidence accompanied by intervening outbuilding of the land until the shallow sea was displaced, or it may mean actual alternating positive and negative movements of the sea bottom with the sum total strongly negative, for it is clear that there was a gradual subsidence in the area of Pennsylvanian sedimentation as time elapsed.

The significance of the different lithologic types which are observed in the sequence of limestones and shales as described in the Oread formation is not at all clear. It is believed, however, that all of the phases are related to stages of the transgression and regression of the sea rather than subordinate vertical oscillations of emergence and submergence. If these conclusions are correct, it follows that the entire limestone and thin shale sequence and the adjacent thick sandy shale with occasional coal beds constitute a single cycle or rhythm, which accordingly may correspond to one of the cycles identified in such a region as Illinois. I believe that the basins in which the Pennsylvanian is now found somewhat separated from one another were formerly joined together, and that conditions in one part of the general basin are related to those in other parts. If this is true, a definite relationship may be expected between the types of cycles which have been described in the eastern interior and those which are found in the western interior basin.

---

[2] John L. Rich, personal communication.

SUMMARY

The Pennsylvanian strata of the northern mid-continent region consist of alternating shale and limestone with minor sandstone beds. Thin stratigraphic units are remarkably persistent horizontally. The thickness of the strata increases southward and there is evidence that the sediments were mainly derived from the south. Evidence of cyclic sedimentation is seen in frequent and rather regular alternations from marine to nonmarine conditions but especially in a peculiar sequence of distinctive types of limestones and shale that is repeated several times. Some parts of the Pennsylvanian section lack evidence of such cycles. The significance of the sequence is not known, but the cyclic changes of sedimentation that are observed in the northern mid-continent area are believed to correspond to cyclic changes in Illinois and states to the east. Ultimately it should be possible, if this is true, to make definite correlations of the Pennsylvanian strata of these and other regions, formation by formation and in some cases perhaps even bed by bed.

PENNSYLVANIAN SEDIMENTATION IN TEXAS

By F. B. Plummer[2]

ABSTRACT

The Pennsylvanian strata in Texas comprise four divisions. The lower Bend group which is made up of massive limestones and shales derived from a low land mass situated to the east does not exhibit typical cycles or rhythms in its sediments. It represents about one-half the period, judged by the development of its ammonites. The succeeding three groups offer a great diversity of sediments derived from folded and faulted ridges on the east, the Balcones ridges, and a mountain range on the north, the Wichita Mountains. The deposits of the upper groups in the south end show typical rhythmic sedimentation. In passing northward the sediments change markedly as the mountains are approached, and the rhythms are obscured by a greatly increased amount of coarse material. It is concluded that in Texas the rhythms are of local rather than regional value in classification of formations, but nevertheless are of much importance in the interpretation of sedimentary history.

INTRODUCTION

The application by Marvin Weller[3] of the conception of repeated cycles in Pennsylvanian sedimentation to furnish a more natural basis for subdividing and classifying the strata in Illinois is praiseworthy. His suggestion that cyclical repetition of beds is widespread and therefore of value for the correlation of strata in different Pennsylvanian areas deserves serious consideration by stratigraphers. If the cycles prove continuous over continental areas, the division of Pennsylvanian time into its cycles will mark a brilliant forward step in stratigraphic research.

Already the repetition of a series of Pennsylvanian sedimentary beds to form cycles or rhythms[4] has been recorded for a number of areas[5] outside

---

[1] Published with the permission of the Director, Bureau of Economic Geology, University of Texas, Austin, Texas.

[2] Bureau of Economic Geology, Austin, Texas.

[3] Weller, J. Marvin, Cyclical sedimentation of the Pennsylvanian period and its significance: Jour. Geol., vol. 38, pp. 97-135, 1930.

[4] The author prefers the term **rhythm** to **cycle**, since this has already been established in usage by authorities to describe repeated occurrence of a series of similar sedimentary layers. **Rhythm** conveys the idea of recurring repetition of similar events; **cycle** the completion of a round of events ending at the starting point.

[5] Hind, Wheelton, The Carboniferous rocks of the Pennine system: Proc. Yorkshire Geol. Soc., n. s., vol. 14, pt. 3, p. 449, 1902.

Hudson, R. G., On the rhythmic succession of the Yoredale series in Wensleydale: Proc. Yorkshire Geol. Soc., n. s., vol. 20, pt. 1, pp. 125-154, 1924.

Moore, R. C., Sedimentation cycles in the Pennsylvanian of the northern Mid-Continent region: Abstracts of papers offered at the 42nd annual meeting of Geol. Soc. America, p. 19, Dec., 1929.

Wright, W. B., Handbook of the Geology of Great Britain, edited by J. W. Evans and C. J. Stubblefield, Thos. Murby & Co., London, p. 253, 1927.

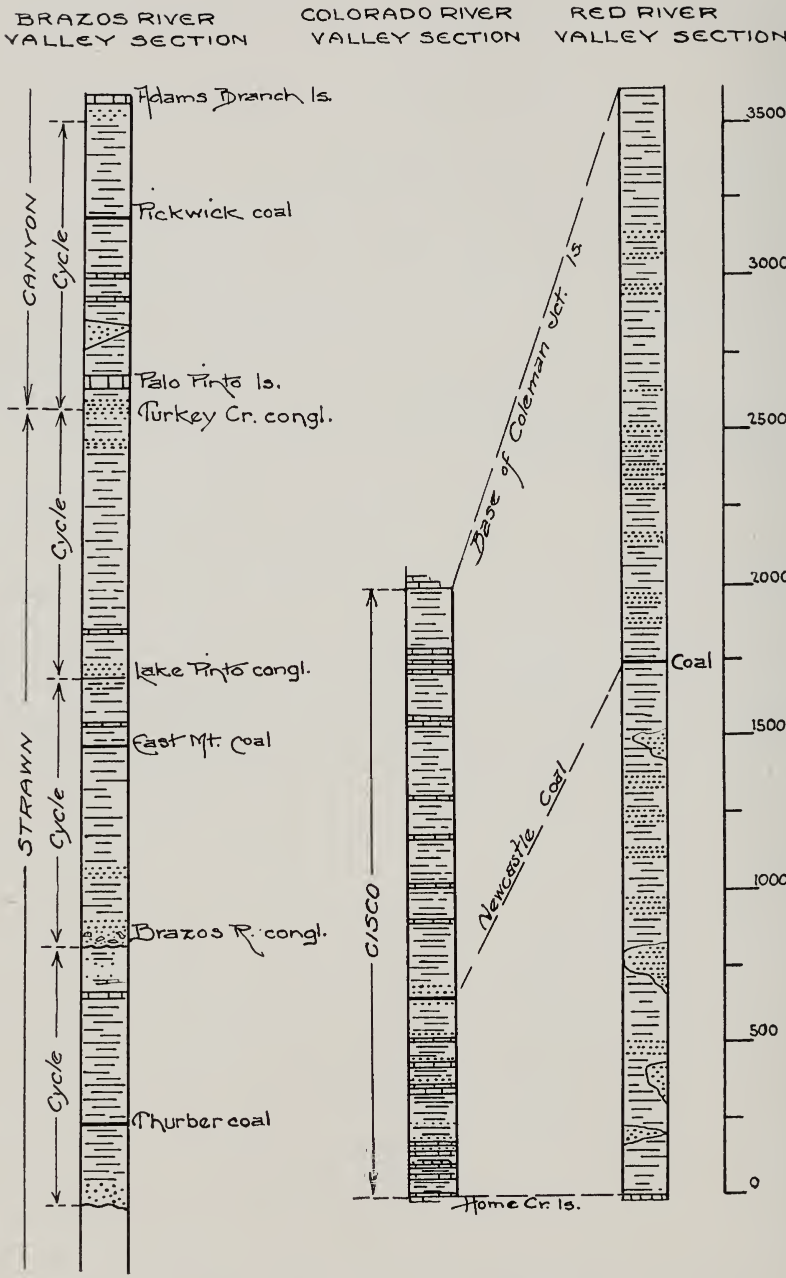


FIG. 56. Geologic sections of Strawn, Canyon, and Cisco groups.

Illinois. It is the purpose of this paper to furnish a brief account of Pennsylvanian sedimentation in Texas and to point out where and to what extent the rhythms or cycles are present.

The Pennsylvanian strata in Texas have been divided into four major divisions: the Bend group at the base, overlain unconformably by the Strawn

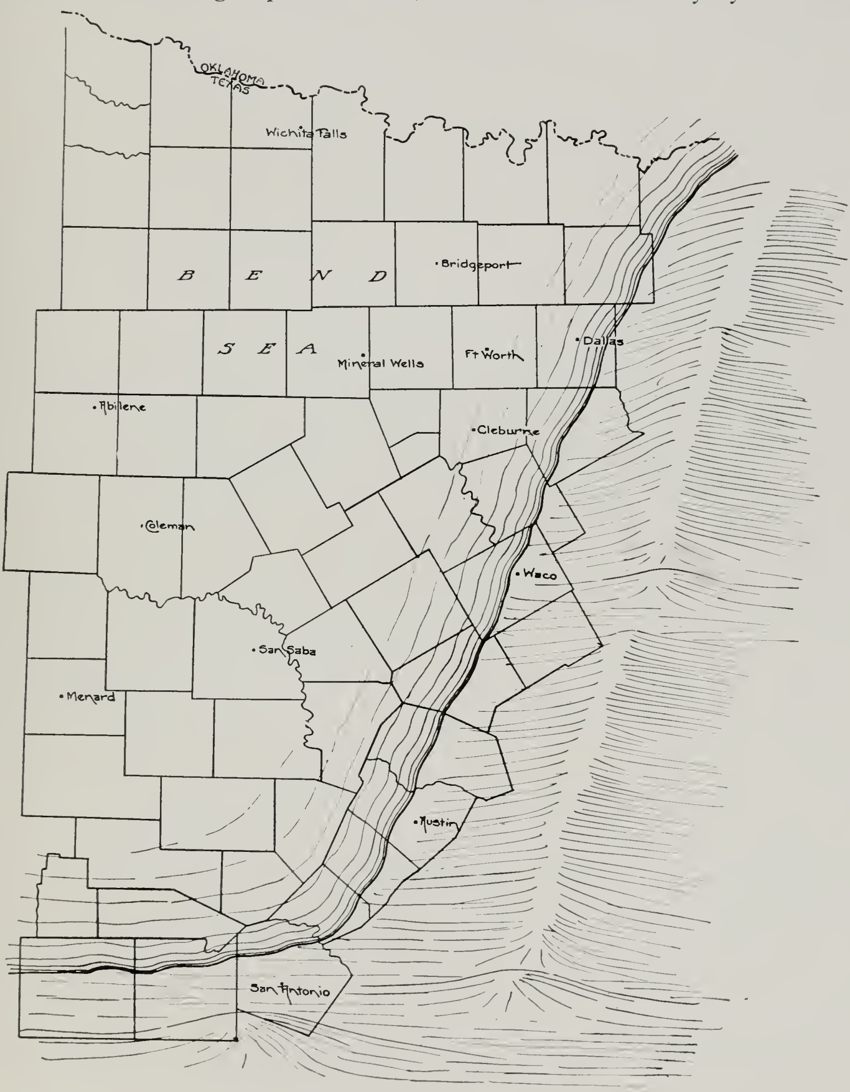


FIG. 57. Paleogeography of the Bend epoch.

group, which is succeeded by the Canyon and Cisco groups. The succession, lithology, and relative thicknesses of these groups are shown in the sections (Fig. 56).

The Pennsylvanian period of deposition in Texas opened with a broad. shallow sea, which stretched from north to south across the central part of the state and extended northward into Oklahoma and westward for an unknown distance (Fig. 57). The source of the sediments was from the east. The bordering land was low. The rocks undergoing disintegration and transportation were massive limestones of Ordovician and possibly Devonian age. Most of the resultant sediments were fine grained, calcareous, carbonaceous, and black. The strata, known as the Bend group, comprise about three-quarters limestone and one-quarter fine carbonaceous shale. Limestone predominates in the lower three-fourths of the series and shale in the upper fourth. The section ranges in thickness from 800 feet in the western part of the Pennsylvanian area to 1500 feet in the eastern part (Fig. 58). The Bend succession of sediments bears no evidence of rhythmic deposition. The

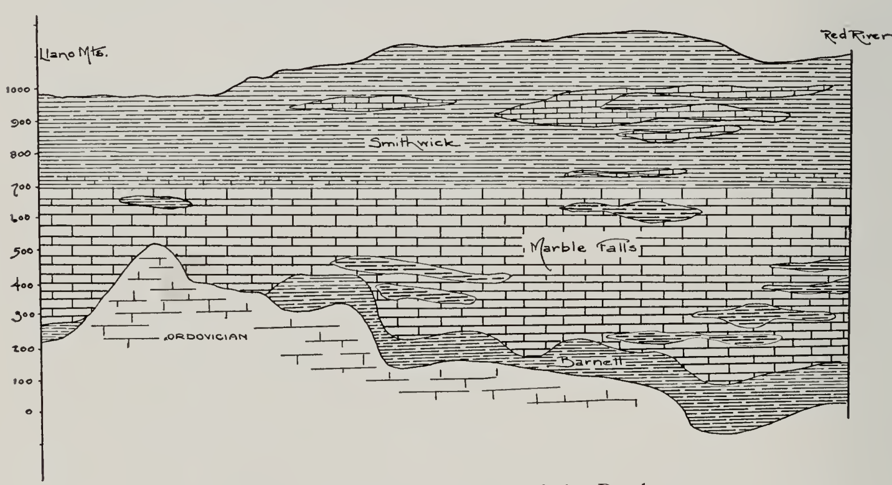


Fig. 58. Geologic cross-section of the Bend group.

strata are wholly thick limestones or thick beds of shale intercalated with thin lenticular limestone layers.

The duration of deposition of these fine black Bend sediments was long. In terms of the length of the Pennsylvanian period in Texas, it occupied at least one-half, perhaps as much as three-fifths of the time period. In terms of the development of ammonoids, it lasted from the beginning of *Goniatites* through *Gastrioceras, Homoceras,* and *Paralegoceras,* to *Strawnoceras* n. gen. (ms.).

At the end of the Bend epoch in Texas a great tectonic revolution gave rise to the Bend arch and the Mineral Wells geosyncline. Compressional folding and faulting of the Appalachian type took place along a northeast trend extending from Oklahoma to central Texas along the present Balcones zone of faults. The aspects of the geography of this epoch are indicated in the sketch (Fig. 59). The newly formed structural ridges became the source of the Strawn sediments. The rocks forming the structural ridges were

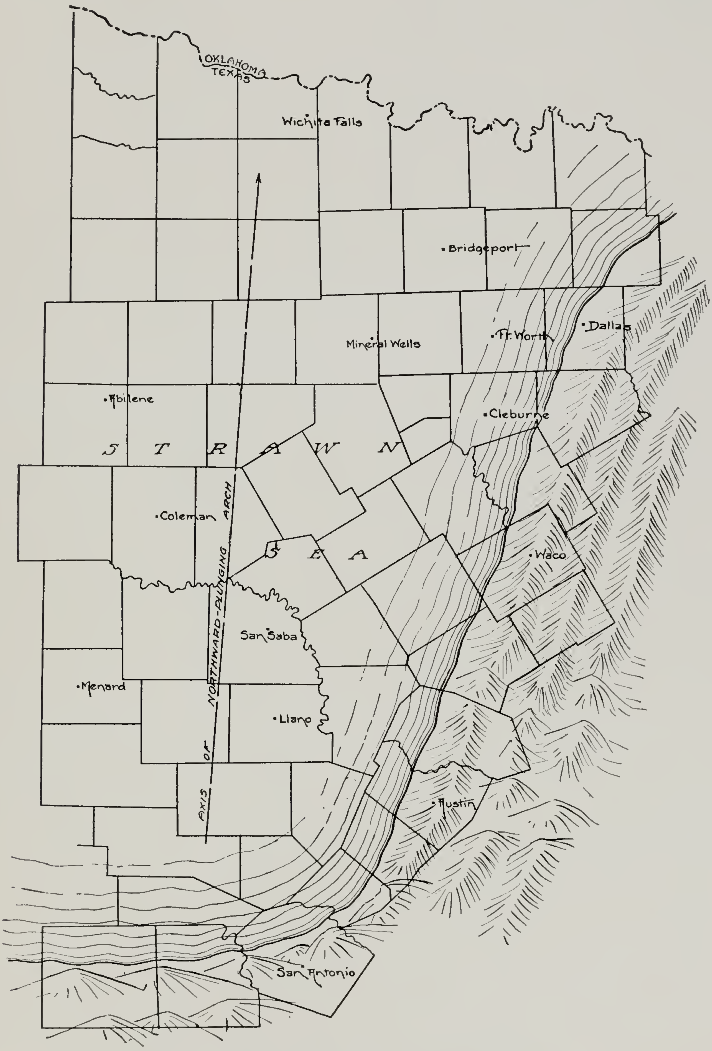


FIG. 59. Paleogeography of the Strawn epoch.

composed of sandstones, quartzites, black slates, and novaculites, similar to the Jackfork and Stanley formations of Oklahoma. They were probably of Mississippian or Devonian age.[6] Pebbles, coarse and fine sands, and

[6] It has been suggested that the eastward edge of the Bend strata upturned in the deformation may have furnished much of the material. A very careful and detailed examination of the pebbles and grains of the Strawn conglomerates, however, does not reveal any material that can be referred to the Bend.

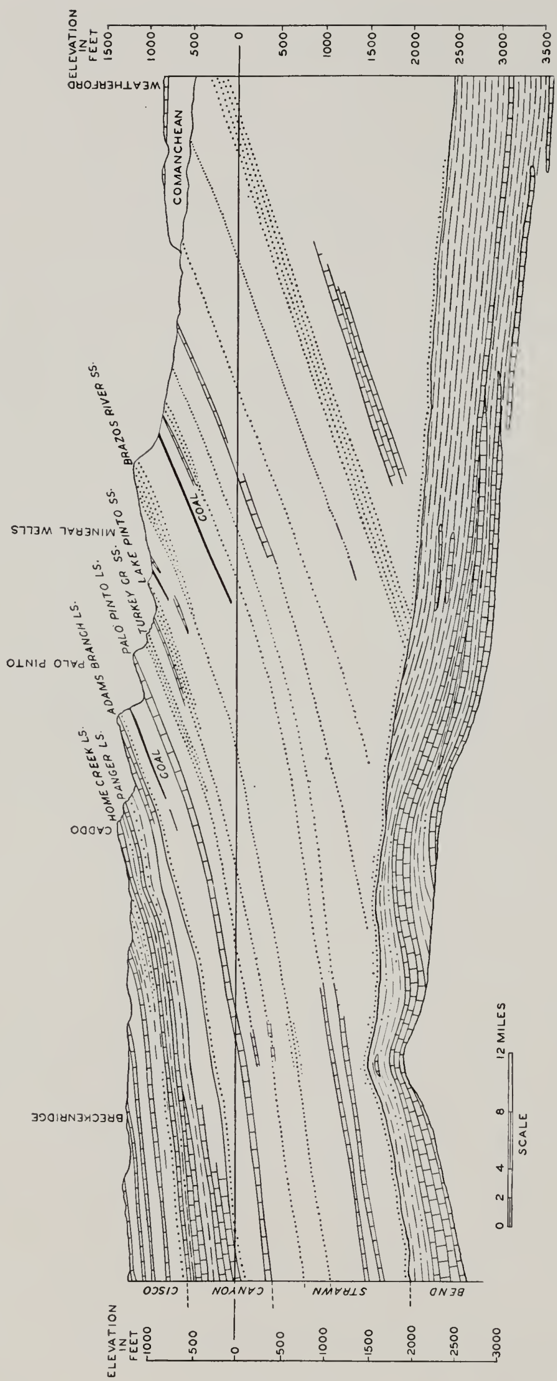


Fig. 60. East-west cross-section showing the relation of the Strawn, Canyon, and Cisco groups to the underlying Bend group.

silts were washed out from the mountain ridges and deposited on an inclined alluvial plain, reaching down into the waters of an inland sea. The basin was deepest along a line drawn from Cleburne to Bridgeport and became shallower from this line southwestward toward the axis of the Bend arch[7] (Fig. 60). Some evidence indicates that the highest portions of the Bend arch were at times islands in this sea.

The series of sediments deposited during the Strawn epoch comprise sand, gravel, clay, and a little limestone in the proportions six-twentieths sand and gravel, thirteen-twentieths clay, and one twentieth limestone. In the eastern part of the basin about four-fifths of the strata were deposited in marine waters and are more or less fossiliferous. The remaining one-fifth was deposited on land as great piedmont alluvial fans, which spread into the sea as subaqueous delta fans. The lower beds of the Strawn, made up mostly of sandstones and sandy shales, are not well known, since they are covered by younger formations. The middle portion carries two or three coal seams, and from these seams upward the successive strata exhibit repeating rhythms. Each rhythm consists of conglomerate at the base overlain by sandstone, marine shale, limestone, and nonmarine shale in upward succession, capped by another layer of conglomerate. Each conglomerate layer appears to have the same origin—a great alluvial fan merging westward into broad delta deposits at the mouths of ancient rivers. The rivers shifted their courses along an inclined plane, so that the fans of one epoch are not exactly superimposed upon earlier fans. These fans are exemplified by the Brazos River sandstone and conglomerate,[8] a member of the Mineral Wells formation in the upper part of the Strawn group. This member lies directly on marine clays and sand and consists of angular chert pebbles in a matrix of sand, grading upward into sand at the top. It is 60 feet thick west of Mineral Wells and can be traced from north to south for 60 miles in both directions. Westward it merges into marine sand. Throughout its extent the upper surface is ripple marked by stream ripples. Above the conglomerate the thick layers of clay are marine in their lower portion and grade upward into nonfossiliferous beds. The lower marine beds contain one or more layers of limestone.

Following the Strawn epoch the subdued Balcones Mountains yielded the finer sediments that comprise the Canyon and Cisco groups. During the deposition of these strata a new locus of folding developed in southern Oklahoma. A thick section lying on the ancestral buried ridge of the Wichita uplift was arched to a position above sea level (Fig. 61). The result was

[7] Cheney, M. G., Stratigraphic and structural studies in North Central Texas: University of Texas Bull. No. 2913, pl. 7, 1929.

[8] Mr. Harry Bay of the University of Iowa has been carrying on a very thorough field and laboratory study of the origin and sedimentation of the Brazos River conglomerate. His researches furnish new authoritative information on these interesting deposits.

that fine sediments from the low Balcones Mountains were deposited in the south end of the basin and coarser sediments from the Wichita uplift in the north end. The sediments from the central and southern portion of the basin exhibit as beautiful an example of rhythmic deposition as one could wish. Heavy ledges of pure limestone capping high escarpments of soft

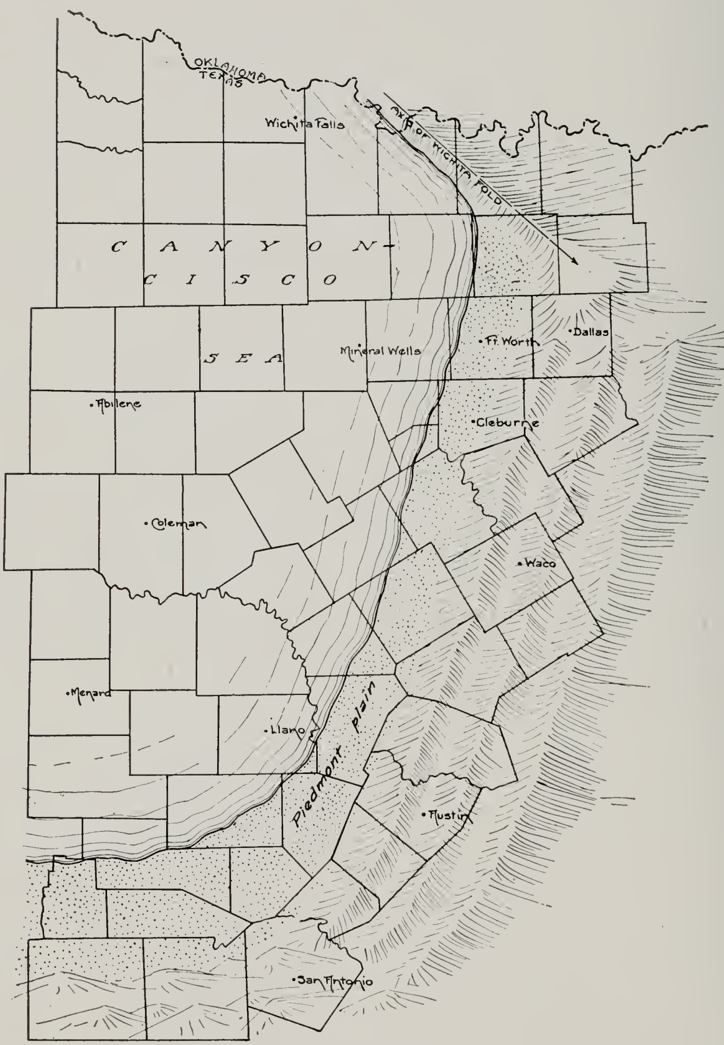


Fig. 61. Paleogeography of the Canyon and Cisco epochs.

shale give to the outcrop the step-like topography so characteristic of upper Pennsylvanian strata. In the northern portion, however, the rhythm is interrupted or destroyed. Throughout the southern part of the basin many of the layers persist for a hundred miles or more; northward these strata change markedly within short distances. In the northern two tiers of Texas counties in the valley of Red River the shales and sandstones attain twice their normal thicknesses, and several new sandstones not present in the south come into the section (Fig. 56). The limestone layers of the southern area thin out northward, then change to peculiar limestone conglomerates or limestone layers composed of angular and solidly cemented limestone breccia. In a few miles farther north this limestone breccia ends abruptly, and the section consists of sandy shales and sandstones only. A few layers of shale are fossiliferous, other layers are nonmarine, and one layer contains thin coal seams.

The limestones of the lower part of the upper Pennsylvanian system in the middle portion of the basin show noteworthy changes also. The Graford formation thickens from 400 to 800 feet northward within a distance of only 30 miles. In the southern part of the Pennsylvanian area this formation contains three limestone ledges from one to four feet in thickness. In the central part of the area these ledges thicken rapidly and merge into a single limestone "reef" 120 feet thick and about five miles long. North of the "reef" the limestones thin out and disappear. The "reef" bears no evidence of having been built by either corals or algae. It is probably a local precipitate of lime deposited in a quiet area in the sea, perhaps near the mouth of a river flowing from an ancient limestone land mass. The waters of this stream were nearly saturated with calcium carbonate and, entering marine waters already highly charged with sulphates, chlorides, and carbonates, became saturated and calcium carbonate was precipitated as limestone in quiet eddies near the mouth of the river. Two such limestone "reefs" have been mapped. One is located in western Palo Pinto County, where the Adams Branch limestone thickens locally from 15 to 230 feet within a distance of a few miles, and the other is in western Wise County where a limestone in the Graford formation thickens to more than 120 feet in an equally short distance.

Thus, although the sediments of the upper Pennsylvanian series exhibit rhythmic deposition, the rhythm does not continue into the northern areas. It is interrupted in some places in the central part of the basin by excessive precipitation of calcium carbonate. In other places the rhythm is obscured by a great influx of sand and sandy shale.

In terms of the length of the Pennsylvanian period, the three upper groups of the deposits occupy at least two-fifths, perhaps as much as one-half, the time. In terms of development of the ammonoids the sedimentation of the Strawn began with the genus *Strawnoceras* n. gen. (ms.), continued through the development of *Schistoceras* and *Shumardites* to *Perrinites*. It is noteworthy that the ammonoids evolved as much during the Bend epoch as during the three succeeding epochs.

In many features the Texas Pennsylvanian section resembles closely the upper Carboniferous and Coal Measures section of England. These widely separated areas exhibit the same ammonoid succession, except that *Shumardites* and its successor *Perrinites* have not been discovered either in Great Britain or in Europe. In England the same dark limestone (Avonian limestone) dominates the lower part of the succession. The overlying Millstone Grit is characterized by thick beds of coarse sand and gravel, above which series in places is a rhythmic succession of shales, sandstones, coal, and thin limestones. The upper Carboniferous in both Texas and England is marked by fans, delta deposits, and by peculiar limestone "reefs."

In conclusion it seems to the writer that the conception of rhythmic deposition as applied to Pennsylvanian sediments in Texas should be regarded as being of local rather than of regional significance. In the Pennsylvanian period, there are two main types of marine deposits, namely: (1) geosynclinal deposits laid down rapidly in epicontinental troughs, and (2) monoclinal deposits laid down slowly along continental borders. The deposits of the first type are laid down rapidly in a sinking basin adjacent to a rising land mass. Under certain conditions this type of deposition is typically rhythmic, the rhythm consisting of a repetition of thin layers of shale, sandstone, marine shale, and limestone in succession. The deposits of the second type are not rhythmic except possibly in narrow belts along continental borders. Such deposits exhibit a zone of coarser sediments along the coast, which finger out into fine sediments, the limestones thickening seaward and the shales landward. This type of deposition is exemplified by the lower Pennsylvanian strata of Belgium, England, and Ireland, and by the Bend group in Texas.

No explanation for rhythmic sedimentation in Texas has yet been suggested. Rhythms occur in geosynclinal areas where rapid sedimentation is caused by rising land or subsiding sea floor or both. The phenomenon seems to be confined to areas where the continental beds from which the sediments are derived are of unequal hardness, such as alternating layers of shale and sandstone. There is no evidence that rhythms occur in areas where the foreland consists only of massive Ordovician limestones or of solid granite masses. With the above conditions as a prerequisite the sequence of events leading to rhythmic sedimentation may be postulated as follows.

(1) Following land elevation, rapid stream erosion of soft materials (shale, et cetera) cuts down to the hard layers where temporary base level is reached.

(2) The streams work through the hard layers and are rejuvenated by deep cutting in the soft layers beneath. The hard layers are rapidly removed by the undercutting attendant upon rapid recession of escarpments, resulting in a rapid dumping in, and spreading out, of the coarser and heavier material

(sand and gravel) over the fine layers. This rapid deposition of shale and sand fills up the basin. The land is brought nearer to base level, and the sea transgresses on the land borders.

(3) Coarse sediments cease to be deposited. In their place limestones form in the sea, and coal beds in the marshes.

(4) The clays beneath are compacted by pressure and dessication of their colloids, the volume of sediments is reduced by a quarter to one-half. The bottom of the sea sinks, the strand line retreats seaward. The streams are rejuvenated and rapid deposition of coarse sediments again sets in. Thus the second rhythm is started. The process will be repeated over and over as long as there is sinking of the sea floor, and as long as there are alternate hard and soft layers on the land to provide sediments.

If the above physical conditions are necessary factors in rhythmic deposition, it follows that such conditions are local and not regional. The rhythms will end where the bordering ridges end or where the lithology of the bordering land mass changes from sedimentary formations of unequal hardness to massive layers or igneous rock. Observations in Texas, Oklahoma, and Great Britain seem to bear out this conclusion. Nevertheless the recognition and interpretation of rhythmic sedimentation is important. The final working out of all the details of these rhythms will lead to clearer conceptions of Pennsylvanian sedimentation and to more natural and more useful classification of Pennsylvanian formations.

Intermission

Continuation of Symposium

Dr. U. S. Grant, *Presiding*

CLIMATIC IMPLICATIONS OF PENNSYLVANIAN FLORA

By David White[1]

INTRODUCTION

In considering the climatic conditions prevailing during Pennsylvanian time in the region of the continent now embracing Illinois, we have to do with an ancient geological epoch and a land pattern very different in size and configuration from that of the present day. The remoteness of the period, as measured by the rate of the atomic disintegration of the uranium minerals, is probably of the order of more than 200 million years. Land connections with Europe gave free migration under climatic zones permitting full interchange between the early Pennsylvanian floras. Families, even the dominant orders of Pennsylvanian land plants, have been extinct since early Mesozoic time. Whole land floras were repeatedly forced to make extraordinary migrations, causing forced adaptations, incisive extinctions, and the development of multitudes of new forms in this region during Pennsylvanian time. The greater part, at least, of the area now occupied by the states appears to have played alternately the role of sea bottom and dry land not less than six, and probably seven or more, times during that period. No remnant of any genus of vascular plants present in the Paleozoic era now survives in any part of the world.

Under the circumstances, therefore, arguments respecting Paleozoic climate can not be based on the geographic distribution of living representatives of identical genera or even families, with the conclusiveness possible in the cases of the late Mesozoic and Tertiary floras. The argument must rest mainly on the general aspect and growth of the flora, and on the structure, the special morphological and ecological adaptations of the plants, and the observed physical features of the environment. Subaerial plants of great size, with rapid growth, indicated by large cells, may reasonably be interpreted as proving adequate moisture; and if thick exogenous growth is com-

---

[1] Principal Geologist, U. S. Geological Survey; also in charge of paleobotanical studies of the Pottsville formation, Illinois State Geological Survey.

posed of cells with relatively thin walls and is not marked by distinct annual rings of reduced cells, we must conclude that neither winter frost nor a season of marked drought offered serious obstacles to continuous expansion. Further, it is safe to assume that climbing ferns with dissected, delicate, or semi-membranaceous pinnules reflect equable, if not actually subtropical temperatures, with well distributed rainfall in Paleozoic time as well as at present. The growth, in the same flora, of clambering, fern-like plants of great length, sprawling among and over relatively lush growth, strongly supports this assumption.

In studying the fossil floras much reserve is demanded in the interpretation of characters of leaf that appear to be xerophytic, for, as is well known, most of the remains of the plant life of Pennsylvanian age which have been collected and studied are drawn from the roof shales immediately over coal beds which are now known to represent swamp deposits in most cases. Too complete saturation of the soil, or alternations of saturation with exposure and drying out of a normally saturated soil, leads to the development of water storage and protective structural and surface features similar to those truly xerophytic, but which are really pseudo-xerophytic. Therefore, in view of the limited knowledge of the internal organization of the Pennsylvanian coal measures plants of North America, it may be wise to place higher values on luxuriance, habits of growth, association, and other features, than upon the detailed characters of the leaf itself.

CHESTER FLORAS

The combined flora of Chester age from Illinois and Indiana is on the whole relatively meager in number of species. *Cardiopteris* cf. *polymorpha* and *Lepidodendron Volkmannianum* are the dominant types, the latter of nearly world-wide distribution in the upper Mississippian of the Northern Hemisphere. This *Lepidodendron* from Illinois and Indiana is perhaps indistinguishable from the Old World type or its representatives in the Appalachian Trough.

The Mississippian plants found in Illinois are hardly to be regarded as swamp types. They are found in cross-bedded sandstones and shales and may have grown in meadow or upland habitats. The fernlike species are mostly small, and the reduced, coriaceous and generally densely villous leaves justify the conclusion that conditions of growth were rather unfavorable. They suggest either that the climate was characterized by severe droughts or that the soil was, perhaps, overdrained during dry seasons. The latter seems less probable. Presumably mountain-building was already in progress, especially in late Chester time. The poverty of the Chester flora and its generally stunted and more or less distinctly xerophytic characters forecast the approaching extinction of the Mississippian types which preceded the introduction of the less meager but nevertheless obviously restricted earliest Pottsville flora. In connection with the consideration of a relatively unfavorable Chester environment, the evidence of the presence of ice in Oklahoma in Caney time may be taken into account.

POTTSVILLE FLORAS

In late middle Pottsville time the region including the Eastern Interior coal field and embracing the coal fields of Illinois, Indiana, western Kentucky, and eastern Iowa, was a broad lowland basin which had been raised above the level of the sea at the close of the Mississippian period. It drained with gentle slope toward the south and southeast, but little subject to aggradation except in its lower part in southern Illinois and southwestern Indiana. The floor of this remarkable, nearly base-leveled region was limestone almost everywhere. There is no evidence of any considerable depositon of sediments in thick soils or alluvial materials in the northern portion of the basin until very near the close of Pottsville time, when a mantle, generally less than 30 feet in thicnkess and but rarely approaching 75 feet, embracing irregular thin sandstones, shales, clays including high grade stoneware clays, one or more thin coals, and an irregular limestone, was spread over the coal field region north of the latitude of St. Louis. Those sediments underlying coal No. 2, conventionally chosen as the base of the Carbondale formation, which is of Allegheny age, represent all the known deposits between the latter and the eroded surface of the Mississippian strata.

The scarcity of quartz pebbles throughout these deposits in the northern area is extraordinary. Those present are mainly confined to the thin residual matter in contact with the Mississippian, where they are in many cases mingled with chert and small fragments of limestone. The source of the quartz pebbles, none of which are large, involves an unsolved research problem.

The oldest sediments of Pennsylvanian age in Illinois were laid down by aggrading streams in the southeastern portion of the State during late middle Pottsville time, when the lower part of the basin, extending across western Kentucky and opening southeastward toward the present Gulf of Mexico, was gradually overspread by sandstones, shales, clays and coals, with marine limestones in the upper part. The lower group of sandstones, the Caseyville, which is sparsely conglomeratic, is approximately contemporaneous with the Sharon of the northern Appalachian trough, but the thin layers of shaly sandstone locally present at the base of the formation belong unmistakably to the middle Pottsville. In age the coal group of the Caseyville is close to the "coal-bearing shale" of Washington County, Arkansas, which, though included in the Morrow group, is not lower Pottsville.

Sands, generally with very little mica, are abundant in these older sediments but are more prevalent in the later Pottsville. On the other hand, mica is plentiful in the sandstones of the basal Carbondale strata.

The full thickness of the Pottsville formation in the southeastern part of the State approximates 1000 feet. Several marine horizons marking stages of progressive subsidence are known, but the basal portion appears to lack them. Four rather widespread limestones are recognized in the upper part of the Pottsville section in the region of southern subsidence. One only of these appears to be represented in the northern, the greater portion, of the Illinois and Indiana coal field, where it lies almost immediately beneath the underclays of the coal called No. 2. This limestone seems to mark the first marine transgression over the northern region in early Pennsylvanian time.

From the time of exposure of the soils beneath the Murphysboro and its supposed equivalents, the Colchester and Morris coals, onward, the whole region of the Illinois-Indiana coal field appears to have moved, with relatively slight differentials, in cycles including exposure, coal formation, submergence, and shale, lime, and sand deposition, with rather extraordinary degrees of parallelism through Carbondale and into McLeansboro time.

Close above the Mississippian surface and mainly in hollows, often underlain by very thin tough deposits of sand, throughout the great northern region of long exposure, lie the high grade (Cheltenham) fireclays, scattered from the St. Louis district to Utica and the northeastern border of the coal field, in Indiana. Their materials were exposed from the post-Mississippian uplift to latest Pottsville time, and were in part, I believe, reworked before final covering.

By the time the earliest Pottsville deposits of Illinois were laid down in the southern part of the State, near the close of middle Pottsville time, Pottsville plant life had developed in great variety and with a remarkable degree of uniformity of floral distribution. The flora of the Caseyville formation belongs to one of the most homogeneous and widespread of all the Pennsylvanian floras. It extends, with many identical species, from southern Illinois throughout the Appalachian region, the maritime provinces of Canada, Great Britain, France, Belgium, Holland, Germany, and Poland, to Italy, Heraclea in Turkey, and the Don Basin of Russia. The flora of this stage is generally marked by the presence of Sphenopterid and Mariopterid species of tropical delicacy or habit. Some of the Sphenopterids are semi-membranaceous and deeply dissected as well as delicate. Several of the plants climbed in tropical fashion; others, embracing especially the Mariopterids, clambered over the more robust types to gain the light in spite of a comparatively luxuriant under-vegetation. It was a time most favorable for coal deposits in many countries, as is illustrated in particular by the lower part of the Kanawha formation of West Virginia.

Most of the fossil plants collected from the Caseyville formation in the southern part of Illinois are associated with coal beds and may be regarded as representing swamp floras. At several points, however, in the northern part of the State, plants of Connoquenessing age are found in deposits which, though palustrian, were probably not growing on acid humic soils. Xerophytic features in the plants of the Caseyville formation are to be regarded as pseudo-xerophytic and as adapted to withstand the moisture-reducing effects of a dry season on a normally wet humic soil, rather than as indicating an environment approaching semi-aridity.

As compared with the contemporaneous plant growth of the Appalachian Trough, the flora of the Caseyville formation in Illinois and Indiana appears to be somewhat less luxuriant, with fewer lianas and membranaceous forms, and with more frequent coriaceous species. Fewer Lepidophytes are present than are found in the Appalachian Trough, although a single species may be abundant at a given locality. This feature harmonizes with the rather more coriaceous aspect of the flora. On the whole, the evidence points rather definitely, though not with certainty, to slightly less favorable conditions for plant growth in southern Illinois and Indiana during Sharon time than in the Appalachian Trough. Although there is no evidence of winter frost or of seasons of marked drought, such as might, in a warm climate, favor the more complete oxidation of the iron, concomitantly with restraint of plant growth, I am inclined to infer that during the Sharon epoch the climate of the Eastern Interior region of North America was slightly less humid than in the Appalachian Trough. Nevertheless, the rainfall appears to have been fairly well distributed, though there was certainly some seasonal variation. This may not have been sufficiently well marked to develop notable annual rings in the trunks of the larger plants.

Paleobotanical data are insufficient for the satisfactory discussion of the climate in southern Illinois in the later upper Pottsville. It may, however, be noted that with respect to profusion of growth, variety, and size, the fossil plants found in the rocks not far above the Caseyville sandstone are apparently comparable with those of the corresponding stage in the Appalachian Trough, although I do not think the plants were on the whole so large, or that the floras were quite so luxuriant. This remains to be more definitely determined.

Remains of the flora that grew on the great limestone plain of the Pennsylvanian basin north of the latitude of St. Louis are found in sandstones or shales, sometimes lying immediately upon, sometimes but a few centimeters above the limestone surface, and in many cases in close proximity to coals or distinctly swamp deposits. Here we find a number of somewhat unique types mingled with species present also in the coal swamps of the south. The uncommon types include, especially, representatives of the genera

Megalopteris, Lesleya, and fernlike types, perhaps referable to the genus *Rhacopteris.* *Cordaites* leaves are particularly abundant in the contact deposits, and with them is frequently associated the fertile Cordaitalian inflorescence described by Newberry as *Antholithes priscus.* Two Lepidodendrons and two Sigillarias, one of which is unknown elsewhere, are present. The fossiliferous deposits, which in age appear to vary within narrow limits, are contemperaneous with the upper Connoquenessing sandstone and the Mercer shale member of Ohio and western Pennsylvania. The fact that many of the species that grew on the limestone soil in this part of the basin are identical with those found in the shales above the upper Pottsville coals in the southern part of the State may be interpreted as indicating that rich ulmic acidity, possibly with saturation of the soil, was not an essential requisite for all of the plants found in the shales immediately overlying the coals.

In passing it may be noted that "xerophytic" characters, which may be peudo-xerophytic, are somewhat more prevalent in the plants growing on the old land surface in northern Illinois than in those lying on top of the thin Pottsville coal beds in the southern part of the State.

In discussing the Pottsville floras it should be borne in mind that the section covering the upper Pottsville in southern Illinois is less than a thousand feet thick, whereas the series of beds of the same age in southern West Virginia, which includes the entire Kanawha formation, reaches a thickness of nearer 1800 feet in southeastern West Virginia and northeastern Kentucky. With sedimentation and subsidence obviously more rapid in that part of the Appalachian Trough than in southern Illinois, we nevertheless have the deposition of coal in relatively thin beds in southern Illinois—a circumstance that conforms to the idea of a less humid environment, but which, nevertheless, may not be due to difference in total precipitation.

CARBONDALE FLORAS

In Carbondale time, which succeeded the Pottsville, the Pennsylvanian flora of Indiana and Illinois appears to have reached its maximum luxuriance. It was probably at about this time that the outlet of the Appalachian basin was to the west into the eastern interior embayment. The vegetation was lush, leaves and trunks were large, and delicate ferns were present in proof of ample rainfall, while the relatively slight development or even obscurity of annual rings bears witness to general equability of temperature. *Ulodendron* reached a rather extraordinary development in northern Illinois in early Carbondale time, but Lepidophytes are relatively scarce in most regions.

The early Carbondale carries several delicate and even somewhat membranaceous species, although they are not common. *Neuropteris* and *Pecopteris* are the dominant genera. Some of the Pecopterids were arborescent, their trunks being known as *Caulopteris* or, when partially stripped, as *Stemmatopteris*. *Alethopteris* is particularly abundant in the Danville coals. The principal Neuropterid, of the *N. Scheuchzeri* type described by Lesquereux as *Neuropteris hirsuta,* is notably robust in the roof of coal No. 2 in the Morris region, where, in a favorable environment, it appears to have developed remarkably heterophylly, some of its phases having been described as species of *Odontopteris*. The Carbondale was the epoch of maximum coal deposition in the Eastern Interior basin, as it was also in Iowa, Missouri, Kansas, and Oklahoma.

Although Carbondale climate was very mild, almost certainly without frost in Illinois, it is likely that the rainfall, while abundant, varied seasonally in such degree as notably to affect the water cover or saturation at the surface of the coal-forming swamps. Pronounced seasonal droughts seriously arresting plant growth do not appear to have been the rule—at least before McLeansboro time, yet the water cover was not sufficiently stable to encourage development of the heterosporous Lepidophytes.

McLEANSBORO FLORA

Concerning the fossil floras of the McLeansboro formation little is known, due probably to insufficient effort to collect fossil plants from this part of the geologic column, which is due in turn to lack of coal mines therein. According to the meager data in hand, it would appear, however, that the plants above coal No. 7 offer no particular contrast with the floras of coals No. 6 or No. 7, although representatives of the *Neuropteris ovata* group appear very much more abundantly. Apparent disappearance of the heterosporous lycopods seems to conform to the climatic changes reflected also by changes in the sediments. Roughly, the deposition of redbeds in Illinois appears, according to none too complete paleontological correlations, to correspond in time rather nearly to the beginning of redbeds deposition in the lower Conemaugh of the Appalachian trough. Portions both of the Conemaugh and of the Dunkard group, which also carries thick redbeds members in the Appalachian trough, are marked by the presence of generally thin coal beds. On the other hand, that part of the Pennsylvanian anthracite series that is of Conemaugh age carries workable coals and lacks redbeds. That coal deposition in McLeansboro time was even much less than in the Conemaugh of the Appalachian trough is due, I believe, either to less rainfall in the Illinois-Indiana region or to less even distribution of precipitation throughout the year. I am inclined to believe that both factors obtained. The increasing redness of Conemaugh and Monongahela beds from east to west harmonizes with this conclusion.

EVIDENCE OF THE COALS

Coal is a product of the very complex reaction of a varied environment on the plant growth and its sedimentation. I have noted some evidence that the climate of the Pottsville was, for some of the time at least, slightly less propitious for the luxuriant plant growth in the Illinois-Indiana region than in the Appalachian trough. From the lesser thickness of the coal beds of the Mississippi Valley a similar conclusion may tentatively be drawn if it be assumed that conditions other than climate were the same in both regions. In any event, the generally greater proportion of fusain in the coals and the rather fewer heterosporous Lepidophytes, taken together with the generally more marked xerophytic or, more probably, pseudo-xerophytic character of the plants, point rather distinctly to a less even distribution of the rainfall through the year—that is, to a somewhat drier season. The latter conclusion is more firmly grounded than the view, to which I lean, that the mean precipitation was also somewhat less in the upper Mississippi Valley than in the Appalachian region, although the difference in total rainfall may have been less than now.

CLIMATE AS INDICATED BY FUSAIN

Most, at least, of the Illinois coals carry very great amounts of "mineral charcoal" ("mother of coal" or fusain) which covers the laminæ through considerable thicknesses of the benches. In fact fusian appears, on the whole, to be rather more abundant in the coals of Allegheny age in the coal fields of the upper Mississippi Valley than in the Appalachian basin, and it is much more plentiful than in most regions of Cretaceous and Tertiary coals of the western states. The great quantity and the mode of occurrence of this fusain, which carpets completely so many of the bedding planes in Illinois coals, sometimes forming layers nearly half a centimeter thick (and rarely more than one centimeter thick), involve an unsettled problem of great significance as well as interest. In view of the nature of the debris represented in the fusain, its configuration and position, and its incredible quantity and extraordinary relative evenness of distribution over the bedding planes, now marked by laminæ, the origin of the fusain in Illinois coals can not be explained satisfactorily either by forest fires on the land outside of the swamp areas nor by fires spreading over enormous areas of the peat-forming swamps with a frequency that for periods, at least, may have been annual. Transportation by wind or water from the upland to the swamp predicates a comparative evenness of distribution of the mineral "charcoal," without corresponding intermixture of terrigenous sediments, that would be nothing short of miraculous. Fires on the swamps, the less impossible of the alternatives, would certainly have produced irregularity of deposition, with burned out hollows containing pockets of inorganic mineral residues. The theory advocated by the writer for some years is that the layers of fusain represent wood fragments and other debris of vascular plants scattered on the surface of the deposit, first more or less fully impregnated with the concentrating ulmic solutions, and then dried out during seasons of periodic reduction of the water level. Owing to the toxicity of the biochemical ulmic products, which may have become insoluble before the peat surface was again covered by water, the bacterial decomposition of this debris would not go further when again the surface was submerged. This theory, though not yet fully confirmed, not only is not disproved, but appears best to meet the critical requirements. If it is correct—all field and laboratory studies add confirmative evidence—the fusian layers, which I regard as probably annual, lend support to the conclusion, drawn from other evidence, that the region was subject to seasonal fluctuation of rainfall.

On the other hand, if it be assumed that the fusain is actually charcoal resulting from fires, as is believed by most engineers and geologists, it follows that there were seasons or irregular periods, really of great frequency, of marked drought, during which forest fires ranged on the upland or even over truly enormous—incredibly large—areas of the lowland swamps. Such a degree of dryness, if seasonal, should have prevented all formation of coal beds through the subaerial oxidation of the organic matter. In fact, unless the temperature were cold even in summer—which was not the case—we probably should not only have had no coals, but we should have redbeds deposits laid down in deltas and coastal flats in the intervals between the limestones or present coal horizons.

CLIMATE AND CONDITIONS OF LAND AND SEA

The climatic difference between the Interior and the Appalachian regions in Pennsylvanian time appears, accordingly, to have been on the same side as at the present day when the mean rainfall of Illinois is 2½ inches less than that of Pennsylvania and when the autumn months are perceptibly drier in Illinois.[2] This difference is attributed to failure of south winds in the autumn in Illinois.

Both the far greater rainfall and the very much greater equability of the mild climate, which approached subtropical in the Eastern Interior region, should have and undoubtedly did result from the land and sea patterns of Pennsylvanian time. At the present day and under conditions now existing the upper Mississippi Valley gets its rainfall mainly from the south and east, the supply from the west being largely of secondary origin, since it is

[2] Data kindly furnished by Dr. W. J. Humphreys, of the U. S. Weather Bureau, show that for the states of Illinois and Pennsylvania, the respective rainfalls are "Aug. 2.46, 2.52; Sept. 2.93, 3.71; Oct. 3.39, 5.59; Nov. 1.81, 3.39."

due to evaporation from the land rather than from original sea evaporation on the west. Summer rainfall is more largely from the south.

Consideration of the indicated paleogeography of central North America in Pennsylvanian time develops a picture of broad interior basins covered at times with great epicontinental seas—unrivaled stabilizers of temperature as well as important sources of water vapor. In early Pennsylvanian time a low Ozark land lay to the southwest of the Eastern Interior basin, and another, very much larger and possibly very much higher land mass, Llanoria, lay still farther south. Several islands of considerable elevation, located near the present Rocky Mountains, spread from west Texas northward into Montana. Small islands stood in the Great Plains basin, and large islands, not yet well defined, existed in the Great Basin region, beyond which the region of the Pacific Coast States was probably exposed, at least for most of the time. During the intervals of Pennsylvanian limestone deposition the interior seas, presently connected across Iowa, were at their maximum. These should have been intervals of greater humidity. During the formation of the principal coals, these seas were largely, at least, evacuated, with corresponding increase of the land surface. These changes predicate sweeping migration of the land plants as well as changes of climate, both of which could not fail to effect changes in the floral composition and in the species themselves.

An important point, which may have a bearing on possible relative dryness of seasonal character in the Mid-Continent and Eastern Interior regions during early Pennsylvanian time, is the fact that the Pennsylvanian Gulf of Mexico was much farther to the south and very much smaller than that of the present day. Therefore, notwithstanding the probable presence of interior seas to the west of the Pennsylvanian Rockies and the probably moderate elevation of the latter, it is permissible to assume that during the maximum southward recessions of the seas—that is, during the intervals of land exposure and coal deposition—the supply of summer rainfall, presumably drawn then, as now, more largely from the south than during other seasons, was relatively so much less than that at other times as to permit concentration and disappearance of more or less of the surface waters of the vast lowland swamps and the temporary, sometimes extensive, seasonal exposure of the peat formation surfaces.

The question of changes in the seasonal drift of atmospheric moisture as well as that of paleogeography during the intervals of coal formation, demand further examination. In this connection it should be remembered that most paleogeographic maps represent maximum extensions of the sea, with little regard for the recessions. Meanwhile we have, I believe, sufficient evidence that the lamination of ordinary coals reflects seasonal changes, and that the origin of fusain (mineral charcoal) is due to fluctuation, generally seasonal, with periods of deficiency of rainfall and consequent concentration of the "ulmic" waters and the subaerial exposure of extensive areas of the peat formation surface.

PERMIAN CLIMATE

In passing it may be noted that the lower Permian strata of southern Kansas, Oklahoma, and Texas, bear both paleobotanical and lithological indications of distinctly less rainfall, with evidence, also, of hot, relatively dry seasons, which becomes more marked in passing westward as compared with the Appalachian Trough. It is safe to assume that in this gradation of Permian climate, in which summer aridity became more accentuated toward the west as time progressed, Illinois occupied an intermediate position between the Appalachian region and the southwestern regions.

EVIDENCES OF CLIMATE IN THE MORPHOLOGY OF PENNSYLVANIAN PLANTS

By A. C. Noé

The anatomic structure of a plant reflects the climatic conditions under which it is living. This fact holds good for our living flora and there is no question that similar relations between climate and plant structures existed in the past. The more we learn about the fossil plants, the more we are convinced that biological conditions of plant life in the known past were strikingly similar to those of our time. Probably plant development in the period from the later paleozoic, from which the first terrestial plants are known, to our day, represents merely the last stage of an extremely long history, of which only the final chapter is open to us.

If we accept a complete similarity of biologic functions during the entire period of known geologic life, we have to make allowance for the development of certain habits and adaptations during that period.

The different organs of now existing plants react in varying ways upon climatic conditions. Leaves are probably most sensitive, less so are stems and reproductive organs, and least of all are the roots. The reason is that the leaves are most exposed and the roots are least exposed to the influences of climate.

It is not only the anatomic structure of plants that reacts against the agencies of climate, but the entire habitus of the plant, the speed of its growth, its relation to neighboring plants, and the entire composition of the flora, including its relationship to other floras.

From the type of a leaf, we can judge whether the plant has grown in a warm or cold, wet or dry, climate. A soft leaf indicates a moist and warm temperature. If it is thin, leathery, or succulent, it came from a dry climate. Also, large leaves are more often found in the tropics and small leaves in cooler regions. Large cells and intercellular spaces indicate a moist atmosphere, whereas small cells in a leaf are signs of an arid climate. Protection of the leaves against rapid evaporation in dryness are a thick or hairy epidermis (Fig. 62), stomas, which are placed in depressions of the leaf surface, and a large development of sclerenchyma directly under the epidermis. In some tropical ferns, we also find that the young leaves are protected by irregular bracts until they are strong enough to withstand the influences of the weather.

The most pronounced adaptations of the stem to seasonal changes are the annual rings formed in the secondary wood. The cells of the wood formed in summer are larger than those formed during spring and fall, and during the cold season the growth of the wood comes to a complete standstill. Such annual rings do not exist, as a rule, in tropical trees, where the climatic

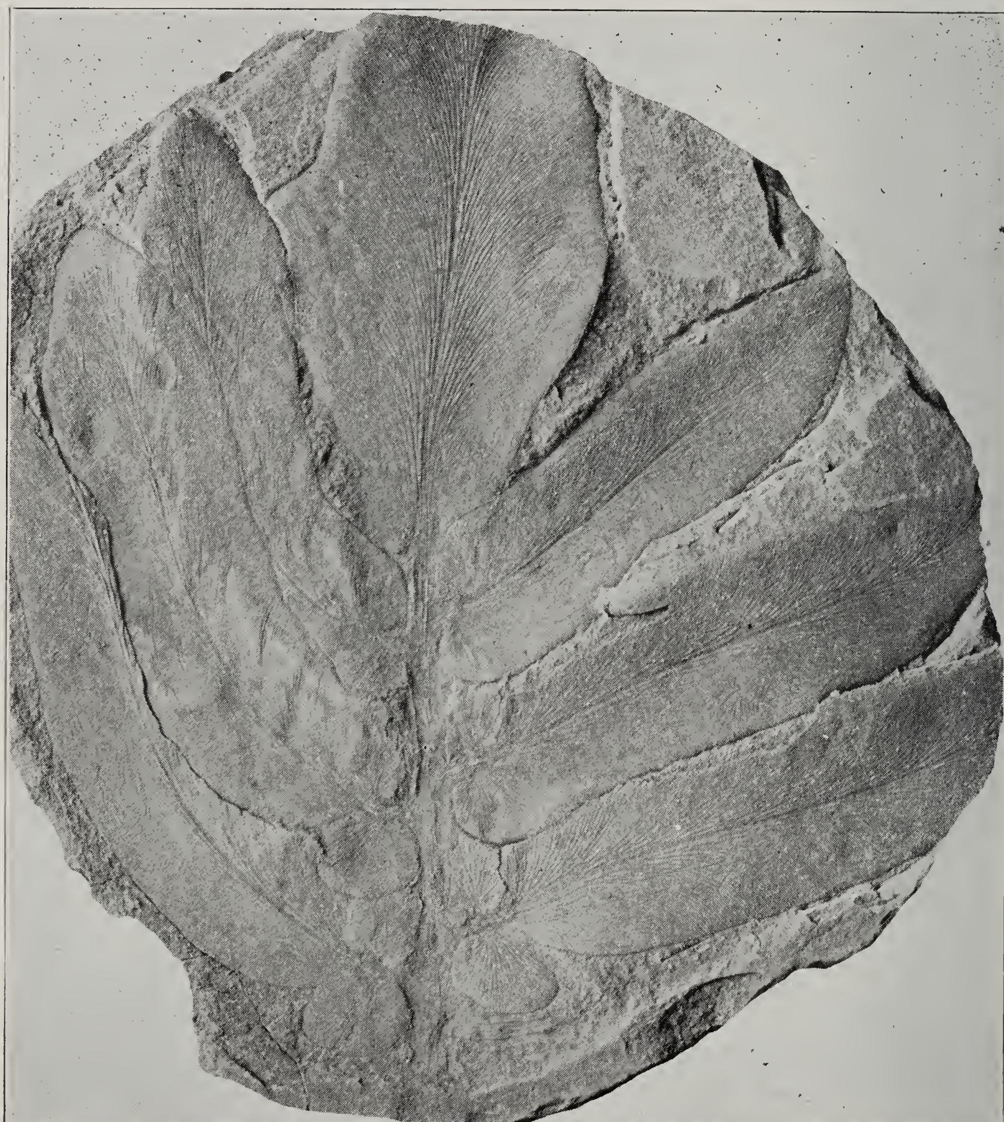


FIG. 62. Pinnules of *Neuropteris decipiens* Lesquereux with hairy upper surface for protection against coolness or aridity. (About two-thirds natural size.)

conditions for growth are uniform throughout the year. But even in the tropics many trees have a rest period during which they stop growing and annual rings are the result. Nevertheless we can always conclude that probably no seasonal changes existed where no annual rings are found.

The wood of trees from warm and moist climates contain few secretory canals, but such canals abound in trees growing in cold climates.

Tropical trees have usually a much developed pith and cortex, whereas trees from colder climates usually contain more wood in proportion to the pith and cortex.

The vegetation growing in a moist atmosphere has usually a reduced cork system and a smooth bark. It also contains a larger number of climbing and epiphylous plants.

The root system is more developed in dryer and colder regions, while tropical plants have fewer roots. In swamps the roots are near the surface because of their need of oxygen, which is not abundant in swamp soil.

As far as reproductive organs are concerned, we notice that many of them are directly attached to the stems in tropical rain forests. The vegetation is usually very abundant in such localities and the leaves, which need the light much more than the flowers, occupy the tops of the trees. The flowers, which do not need the light, are attached in places where they do not stand in the way of the leaves.

Moist and tropical climates and, in general, warm and moist climates, are favorable to large-sized and abundant plants of rapid growth. The colder and dryer the climate, the smaller and sparser is the vegetation.

A considerable amount of information has become available about the morphology of the plants of the Pennsylvanian period. Most of it has been obtained from the study of the coal balls as found in England, France, Westphalia, Upper Silesia, Belgium, Holland, and the Donetz Basin of Russia, as far as Europe is concerned, and lately in this country, primarily in Illinois, but also in Iowa, Kentucky, Kansas, and Texas. In addition to the coal balls, which are either calcareous or silicious concretions found in the coal seam, the roof nodules and loose lying petrefacts, as for instance at Pettycur, in Scotland, have supplied excellent material for microscopic investigations of Pennsylvanian plants.

The coal balls show many leaves belonging to Gymnosperms, Pteridophytes, and Pteridosperms. The Gymnosperm leaves mostly belong to the genus Cordaites. The Pteridophytes are Calamites, Sphenophyllum, Sigillarieae, Lepidodendreae, and Filicales, and the Pteridosperms belong mostly to the genera Lyginodendron and Heterangium.

The same leaves that are found in coal balls are also found in the shales covering the coal, but only in impressions. From these impressions, some conclusions can be drawn in regard to the structure, especially if the epidermis is detachable and can be studied under the microscope. Good shale impressions can be obtained from the above mentioned genera and from numerous others, including the narrow, needle-like leaves of the Equisetales and the so-called Aphlebia, which seem to be large bracts covering the young fern leaves as a protection against the influences of the weather.

The leaves of Cordaites have a fairly compact or dense parenchyma, but the intercellular spaces are not entirely absent. The structure of the

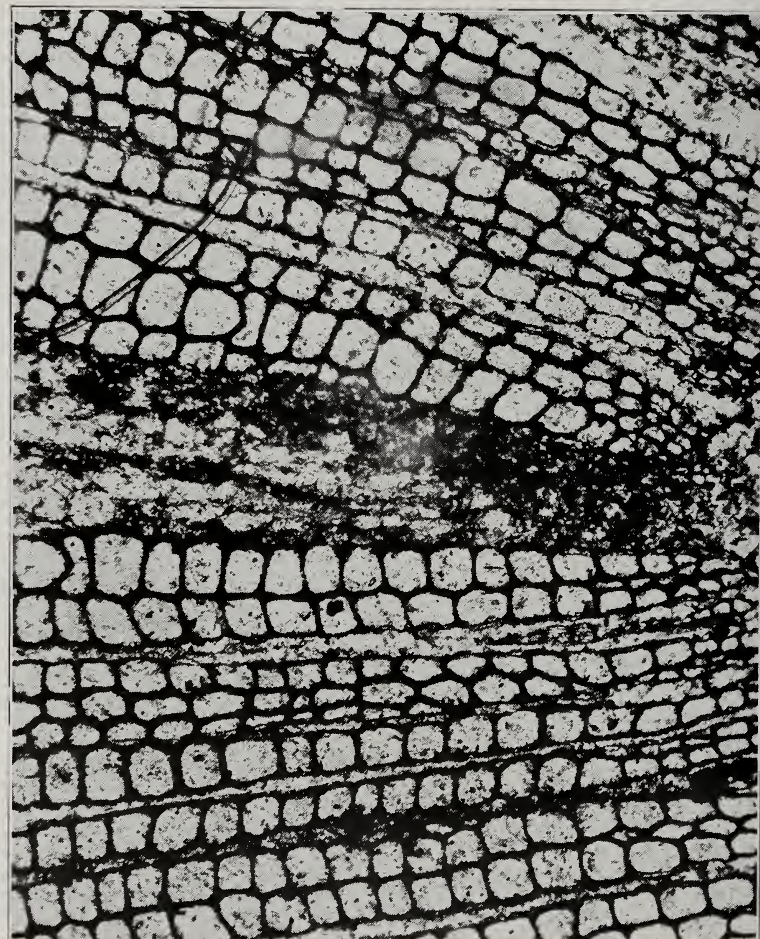


Fig. 63. Secondary wood of *Stigmaria ficoides* (Sternberg) Brongniart, showing no annual rings. (X 100.)

leaves is usually resistant and gives the leaf a bi-facial organization. Sclerenchymas, or strengthening tissues are abundantly represented. Stomas are on a level with the cuticle, and not sunk below the surface. Leaves of such structure would indicate a not very dry, but not excessively moist climate.

The leaves of the Sigillaria and Lepidodendron had the form of succulent needles with two furrows on the reverse side in which the stomas were sunk. When we turn to the leaves of the Ferns and Pteridosperms we notice that they were not leathery like the Cordaites leaves, not needle-like like the Lepidodendron leaves, but large and soft, and only in exceptional cases covered with hair.

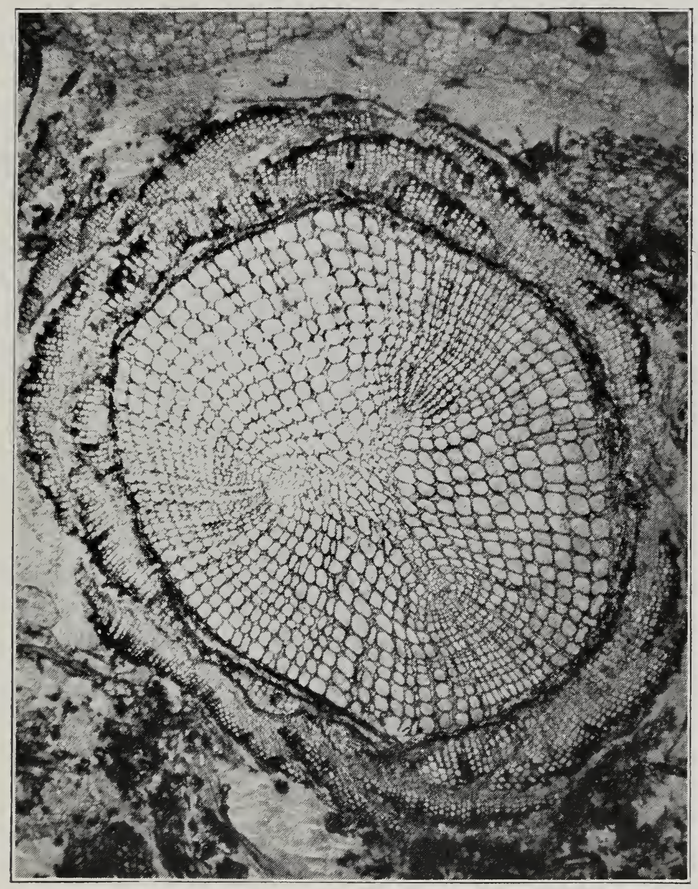


Fig. 64. Primary and secondary wood of *Sphenophyllum plurifoliatum* Williamson, showing no annual rings. (X 40.)

Therefore our conclusion upon climatic conditions drawn from leaves may be summarized in the following way: the tree flora consisting of Cordaites, Sigillaria and Lepidodendron had a more or less xerophytic appearance whereas the ground flora consisting of ferns, tree ferns, and Pteridosperms, distinguished itself by hydrophile characters. We find this combination of two rather opposite types in the modern rain forests, but plant ecologists have not been able to give a satisfactory explanation for it. As long as we cannot fully understand this phenomenon in the contemporaneous flora we should not attempt an explanation for a Pennsylvanian flora.

If we turn to the anatomy of the stems of Pennsylvanian plants we are struck by the almost complete absence of annual rings (Figs. 63, 64, 65). They appear here and there in isolated cases, and may be explained by occasional periods of dryness rather than by seasonal changes. Although annual rings are almost absent in paleozoic stems we begin to see them more regularly in the Keuper and Liassic. They are still clearer in Oolitic woods and are fully developed as in modern times in the Tertiary.

According to David White, the absence of the rings merely indicates a uniform climate which was not only uniform in the same latitudes, but all over the earth at that time, from Bear Island in the arctic region to the regions far south of the equator.

FIG. 65. Secondary wood of *Stigmaria ficoides* (Sternberg) Brongniart, showing rings caused by aridity or through destruction of foliage by insects. (X 4.)

The absence of the rings unquestionably indicates that the Pennsylvanian plants grew in a climate favorable for uniform and continuous growth. There could not have been any seasonal changes of temperature and moisture during the Carboniferous era.

Microscopical examination of Carboniferous wood also discloses few secretory canals.

A very characteristic feature of Pennsylvanian stems, especially of Sigillaria and Lepidodendron, is an unusually small wooden cylinder, and an over developed cortex and pith. The trees must have grown rapidly, which could only have been possible in a very moist warm climate.

In the trees of the Pennsylanvian period we find a rather under developed system of cork tissues and in consequence a smooth bark. The entire structure of some of these trees indicates that they were unable to sustain themselves but had to lean or climb on other trees. To this group belong especially

Sphenopteris Hoeninghause, Heterangium grievei, Mariopteris muricata, and possible Sphenophyllum which may have been a water plant, or a winding forest plant.

Some authors have laid stress on the fact that the blossoms of many carboniferous plants are directly attached to the stem, a structure which is found at present only in tropical rain forests. But this statement holds good only for a comparatively limited group of Pennsylvanian plants like Sigillaria and Ulodendron.

The root system of Pennsylvanian plants is rather under developed compared with that of other plants, also the roots run close to the surface, which may be explained by the lack of oxygen in a swamp soil.

The conclusions which we may draw from the structure of Pennsylvanian plants upon the climate of that period are:

1. It must have been warm but not necessarily tropical.
2. It must have been very moist.
3. It must have been very uniform over the entire surface of the earth.

BIBLIOGRAPHY

Goldring, Winifred. Annual rings of growth in carboniferous wood. Bot. Gaz. vol. 72, pp. 326-330, 1921.

Gotham, W. Paleobotanische Betrachtungen über die fossile Pflanzenwelt. Berlin, 1924.

Knowlton, F. H. Evolution of geologic climates. Bull. Geol. Soc. America, vol. 30, pp. 499-565, 1919.

Köppen, W., and Wegener, A. Die Klimate der geologischen Vorzeit. Berlin, 1924.

Kubart, B. Einiges aus der Biologie der Karbonpflanzen. Paleobotanische Zeitschrift. Vol. 1, pp. 15-25, 1912.

Nathorst, A. G. Sur la valeur des flores fossiles des regions artiques comme preuve des climates géologiques. XIième Congrès Géologique International. Compte Rendu, pp. 743-756, 1910.

Schuchert, C. Climates of geologic time. Smithsonian reports for 1915, pp. 277-311. Washington, 1915.

Schuchert, C. Evolution of geologic climates. American Jour. Sci., vol. 1, pp. 320-324, 1921.

Seward, A. C. Fossil plants as tests of climate. London, 1892.

White, D., and Thiessen, R. The origin of coal. U. S. Bureau of Mines, Bull. 38, 1913.

After this paper was set in type a very interesting article appeared which may be mentioned here but which of course was not used in the preparation of this article:

Giles, Albert W., Pennsylvanian climates and paleontology. Bull. American Assoc. of Petroleum Geologists, vol. 14, pp. 1279-1299, 1930.

INDEX